NOVA

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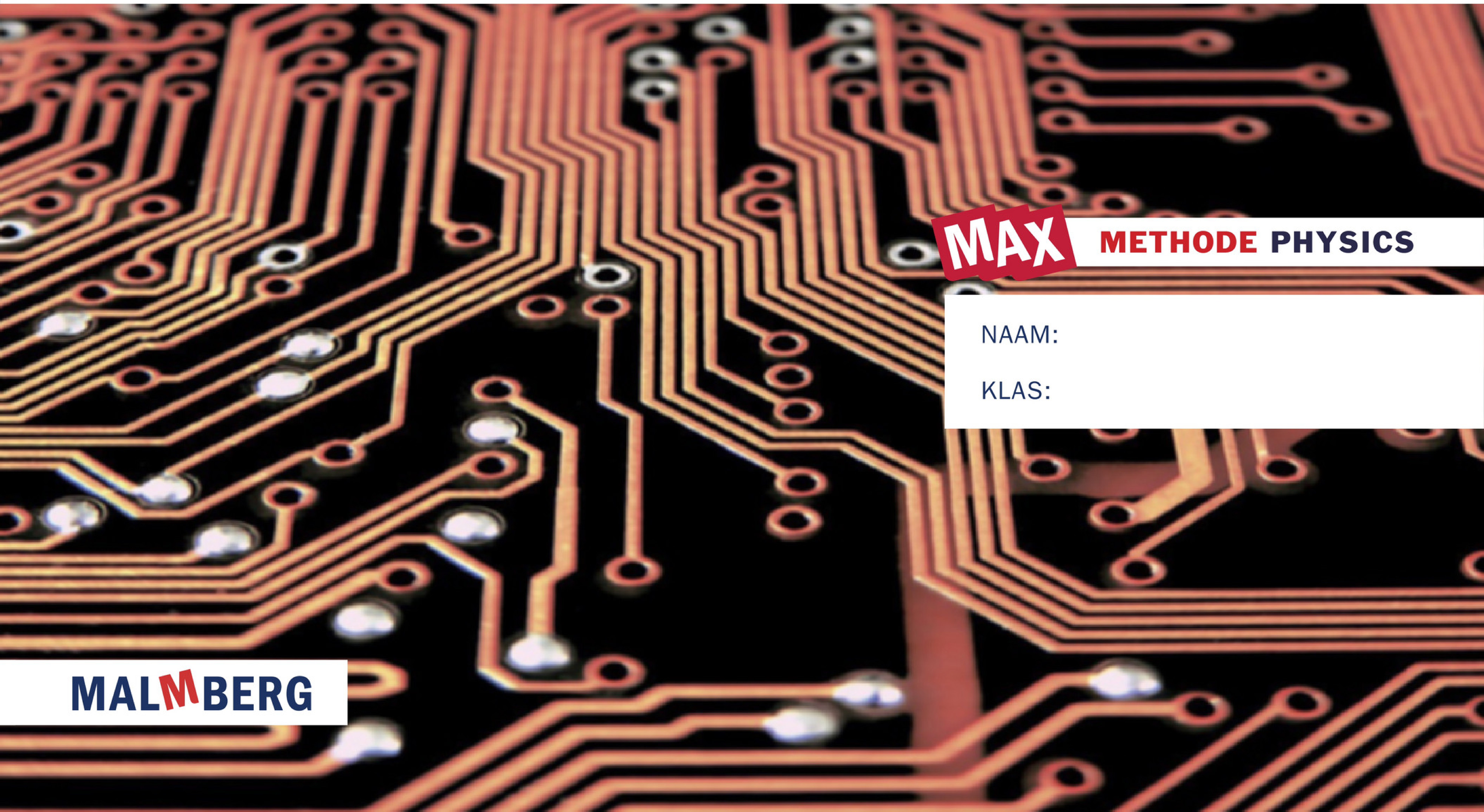
TTO

HAVO | VWO
TEXTBOOK

PHYSICS



MAX METHODE PHYSICS

NAAM:

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NOVA

PHYSICS

3 HAVO | VWO

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Preface

Nova consists of a textbook, digital material and an answerbook.

The textbook covers all the teaching material that you have to learn. There are exercises after each section that will help you remember the material and apply it in practice. The exercises are split up into questions on the course material, which are often taken literally from the theoretical parts of the text, plus questions about practical applications. Some questions are marked with an asterisk (*). These are generally a little more difficult.

Each chapter ends with a number of experiments and Test Yourself questions. There is also a section at the back of the book explaining the skills that you will need for this subject.

The V-trainer in the digital material lets you practice your skills.

Basic material, Plus material and Everyday science
You will go through most of the course material in the book together with the rest of the class. This is the basic material that all the pupils have to know.

At the end of each section, you can find the Plus material. You can go through that if you have any spare time left over when you have finished with the basic material. The Plus material is mostly a bit more difficult than the basic material.

At the end of each chapter there is an 'Everyday science' section, an article in which part of the course material is discussed in a situation from daily life or from a scientific context. These also contain a number of exercises.

Working independently
Nova lets you work independently. You can do the exercises in groups or on your own, you can do the research tasks, or you can use the Test Yourself pages to check how you are doing. Explanations will sometimes also be given to the whole class at once.

If you are working independently, it is a good idea to make a plan.

We hope that you will enjoy working with this book and with the other components of the learning method.

Good luck!

The authors

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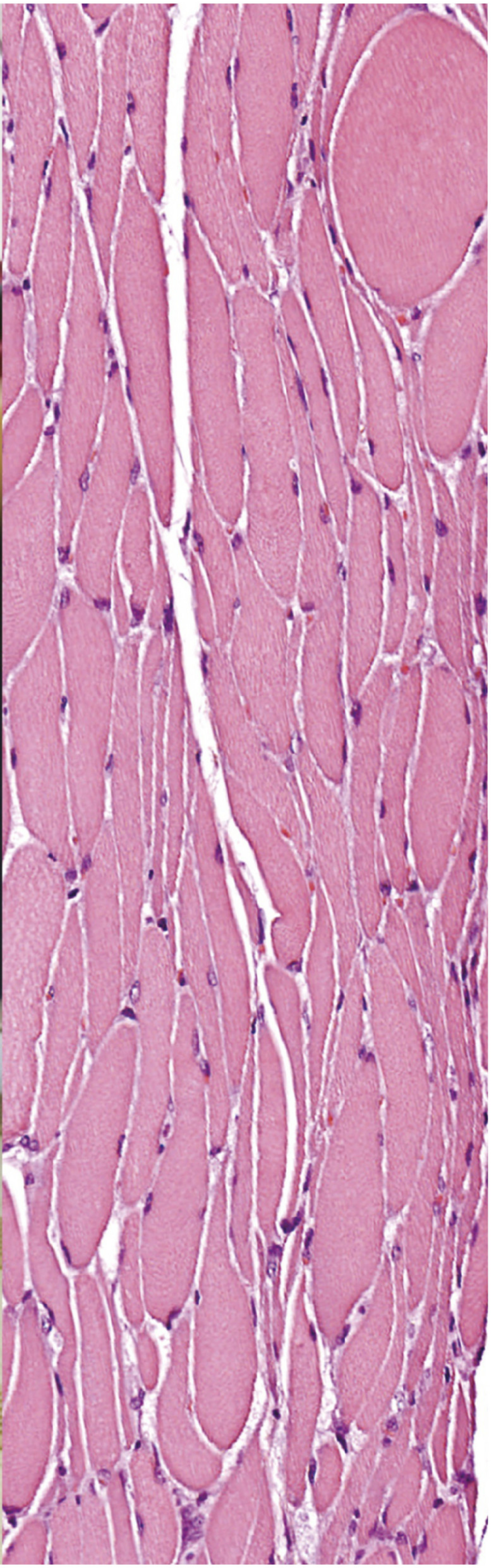

1

Forces

Forces in nature and technology

Forces play an important role in your life. Whenever you walk up stairs, take a bite of an apple or even just breathe, your muscles have to apply forces for you. If your muscles are not strong enough, you use tools to enhance your muscular strength.

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1 Forces around you

Forces play a role in almost everything that you do. Whether you are kicking a football, turning a tap on, pressing a key or taking a bite of a sandwich, your muscles have to apply forces for you.

▲ figure 1
an elastic deformation

Recognising forces

When the force is exerted on your body you can often feel it. For example if somebody gives you a shove or if it is very windy. You cannot see or feel forces that are exerted on other people (or objects). You can only see the effects that those forces have.

Forces can change the **motion** of an object. In a volleyball game that is happening all the time. The speed of the ball increases when a player smashes it. The speed is reduced when a player 'spikes' a hard shot. The direction of the ball changes when players tap or hit it.

Forces can change the **shape** of an object. You see this for instance when an archer draws the bowstring or when a tumbler lands on the trampoline again after a jump. In ball sports, the ball deforms every time it is hit, although that is difficult to see with the naked eye (figure 1).

A deformation can be **elastic** or **plastic**. In an elastic deformation, the object regains its original shape once the force is no longer being exerted. You can see that for instance in a mattress or a bicycle tyre. In a plastic deformation, the shape of the object is changed permanently.

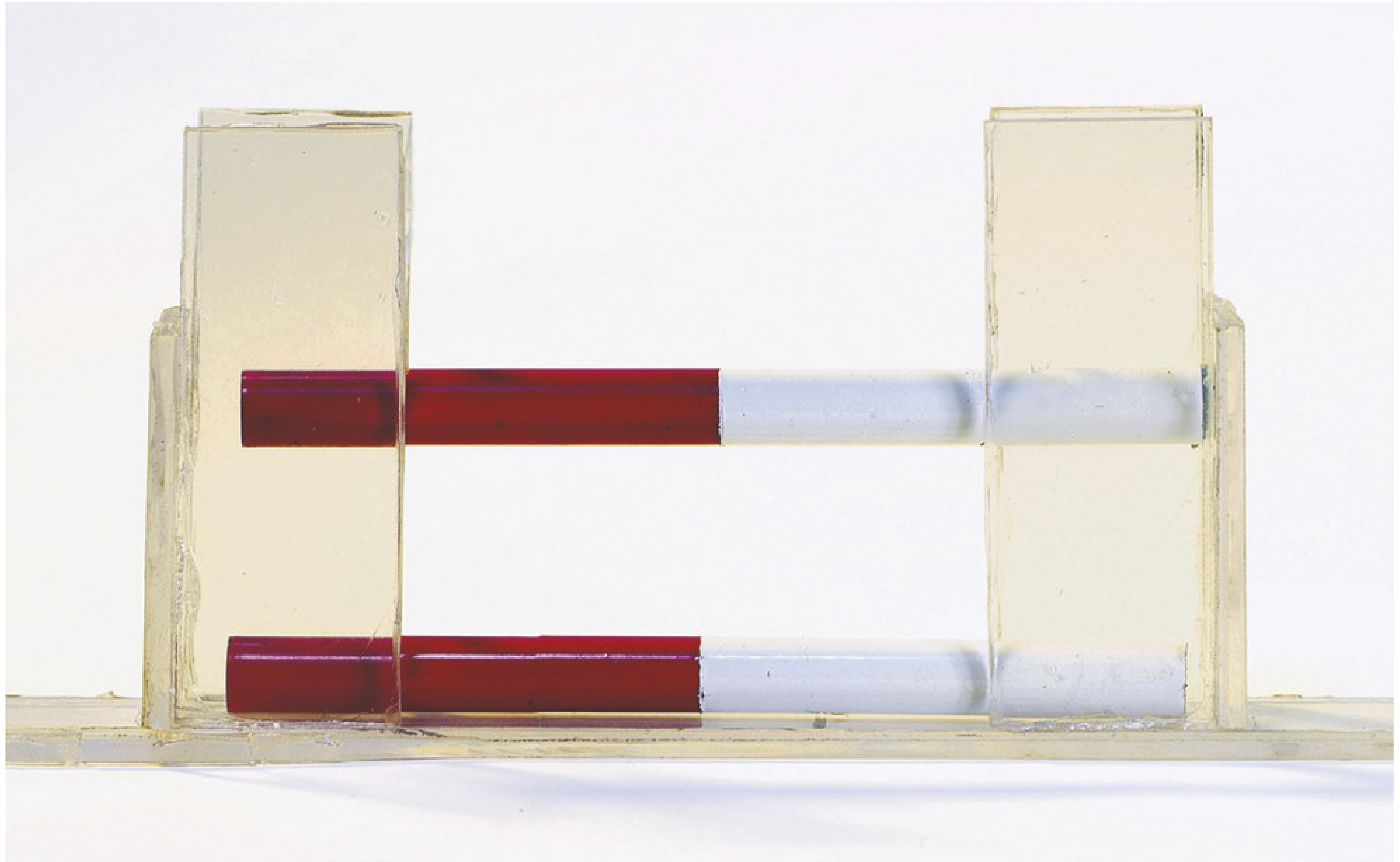
Types of forces

There are all kinds of forces, such as muscular strength, springiness, gravity and magnetism.

- When you throw a softball, your hand exerts a force on the ball. When you cycle, your feet exert forces on the pedals. In both cases, the forces come from your **muscular strength**. These forces are created when the muscles in your body contract.
- When you extend a Bullworker, you can feel the coiled springs pulling against your hands (figure 2). This force is the **resistance** or **resilience**. When you extend or compress a springy material, you can feel it resisting. The resistance disappears again when the material returns to its original shape.

▼ figure 2
An expander lets you feel the resistance.

– When you lift a dumbbell, you can feel how heavy the weights are. If you then let go of it, it will fall straight downwards. That is the effect of **gravity**. Gravity is the attractive force that the Earth exerts on you and everything around you.
– If you hold two bar magnets close to each other, you can feel the **magnetic forces** at the poles (the ends). A north pole and a south pole attract each other, but two north poles repel each other, as do two south poles. This repulsion explains why the top magnet in figure 3 seems to be floating.



▶ **figure 3**
The two magnets repel each other.

Measuring forces

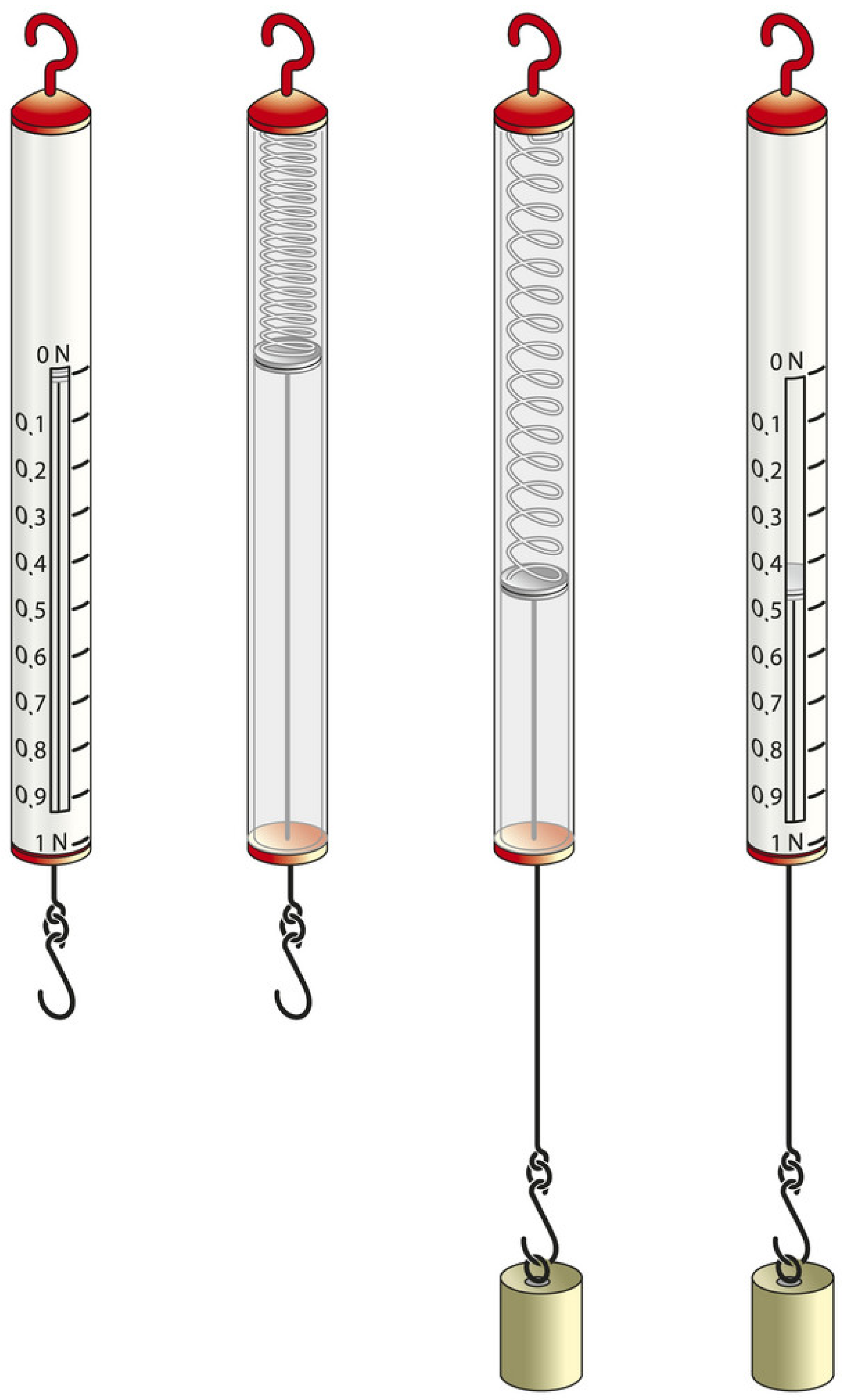
You can measure forces with a **dynamometer**. A dynamometer contains a helical spring. The greater the force pulling on the dynamometer, the further the spring is stretched (figure 4). For measuring large forces, you use a dynamometer with a stiff spring, while for measuring small forces, you use a dynamometer with a flexible spring.

A dynamometer has a scale that is graduated in newtons. The newton (N) is the unit that is used for measuring all kinds of forces, from the attractive force between two magnets to gravity on the Earth's surface. This unit is named after the English physicist Sir Isaac Newton (1642–1727).

On the Earth, there is a simple relationship between gravity and the mass of an object. To determine the force of gravity on an object (in N), you have to multiply the mass (in kg) by 9.8. You can write this calculation rule out as a formula using letters:

$$F_g = m \cdot g$$

In this formula, F_g is the force due to gravity, m is the mass of the object and g is the strength of gravity. The value of g on the Earth's surface is 9.8 N/kg, wherever you are.



▲ **figure 4**
How a dynamometer works.

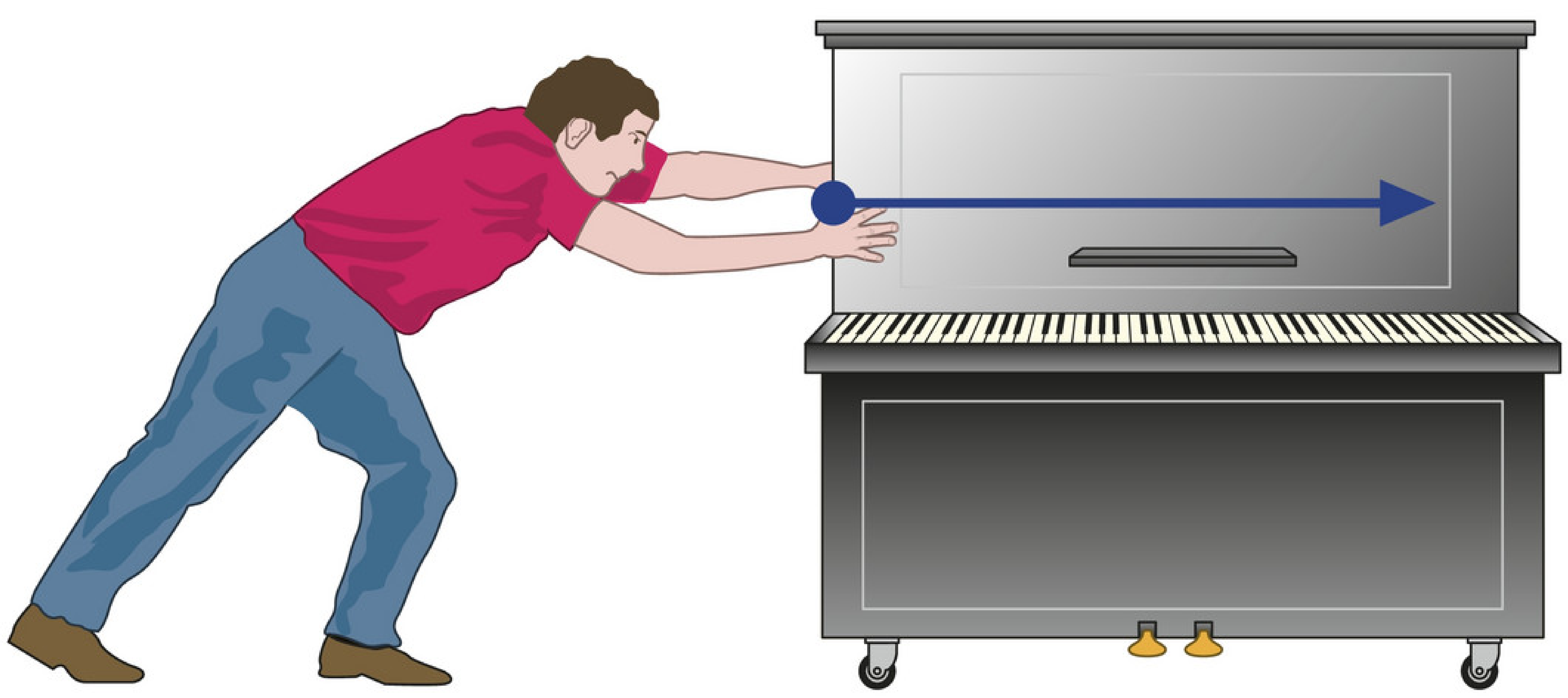
Drawing forces

A force has a magnitude, a direction and a point of application. In physics a variable that has both magnitude and direction is called a **vector**. A vector is drawn as an arrow. Forces are vectors.

- The length of the arrow gives the magnitude of the force.
- The direction of the arrow shows the direction of the force.
- The point of application is indicated by where the arrow starts from.

When you are going to draw in forces, you first decide on a **force scale**. For example, 1 cm ≙ 5 N. That means that an arrow 1 cm long represents a force of 5 N. A force of 15 N using this scale would then be an arrow 3 cm long.

Always think carefully about where you draw the arrow from. If you want to draw the muscular force in figure 5, the arrow should start at the point where the hands are pushing against the piano: that is the point of application.



▲ **figure 5**
muscular forces on a piano

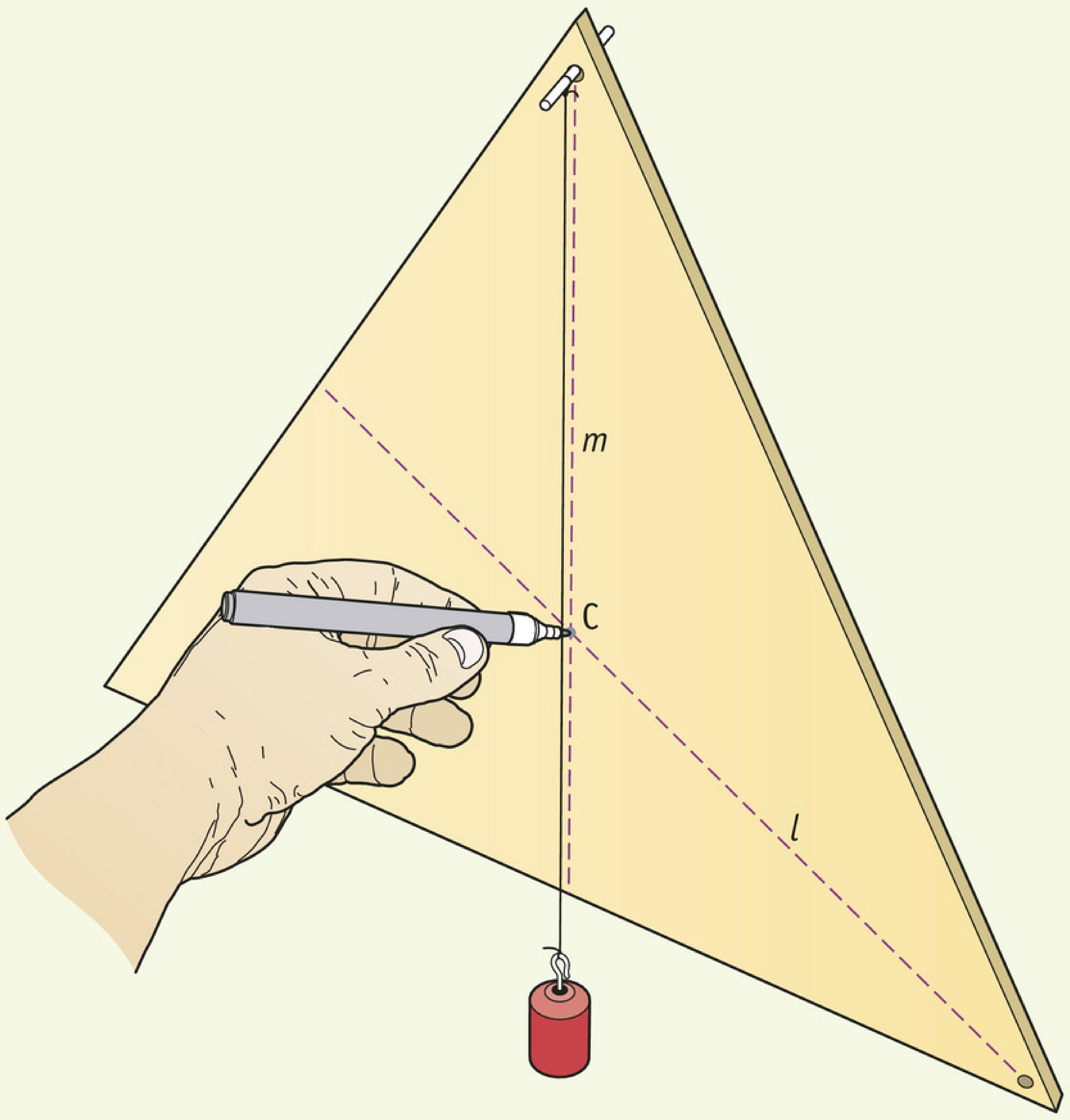
Gravity applies at all points on an object. You should therefore really be drawing lots of small vectors everywhere on the object. To simplify it, however, you choose a single point C which we call the **centre of gravity**.

Plus The centre of gravity

Every object has a centre of gravity. This is an (imaginary) point where you can imagine gravity as being applied. If the object's centre of gravity is above the plane it is resting on, the object is balanced. If the centre of gravity is not above any support, the object will tip.

This is how you can determine the centre of gravity:

- Hang the object up. Use a weight on a string to draw a line *L* perpendicularly downwards from the point it is hanging from.
- Hang the object up again by a different point. Draw a perpendicular line *M* downwards from this second point as well.
- The lines *L* and *M* cross at C, the centre of gravity (figure 6).



▶ **figure 6**
How to determine the centre of gravity.

You can check that C really is the centre of gravity by balancing the object on the tip of your finger. If the object is balanced, your finger has to be directly under C (figure 7).

▶ **figure 7**
A tennis player showing where the centre of gravity of his racket is.

Exercises

1 Answer the questions below.
- **a** How can you see that a force is being exerted on an object?
- **b** What is the difference between an elastic and a plastic deformation?
- **c** How large is the force of gravity on an object with a mass of 1 kg?
- **d** What does the point of application of a force mean? Explain.

2 What three things do you have to think about before you draw in a force vector?

3 A force is an example of a vector quantity.
a Name another example of a vector quantity.
b Name two variables that are not vector quantities.

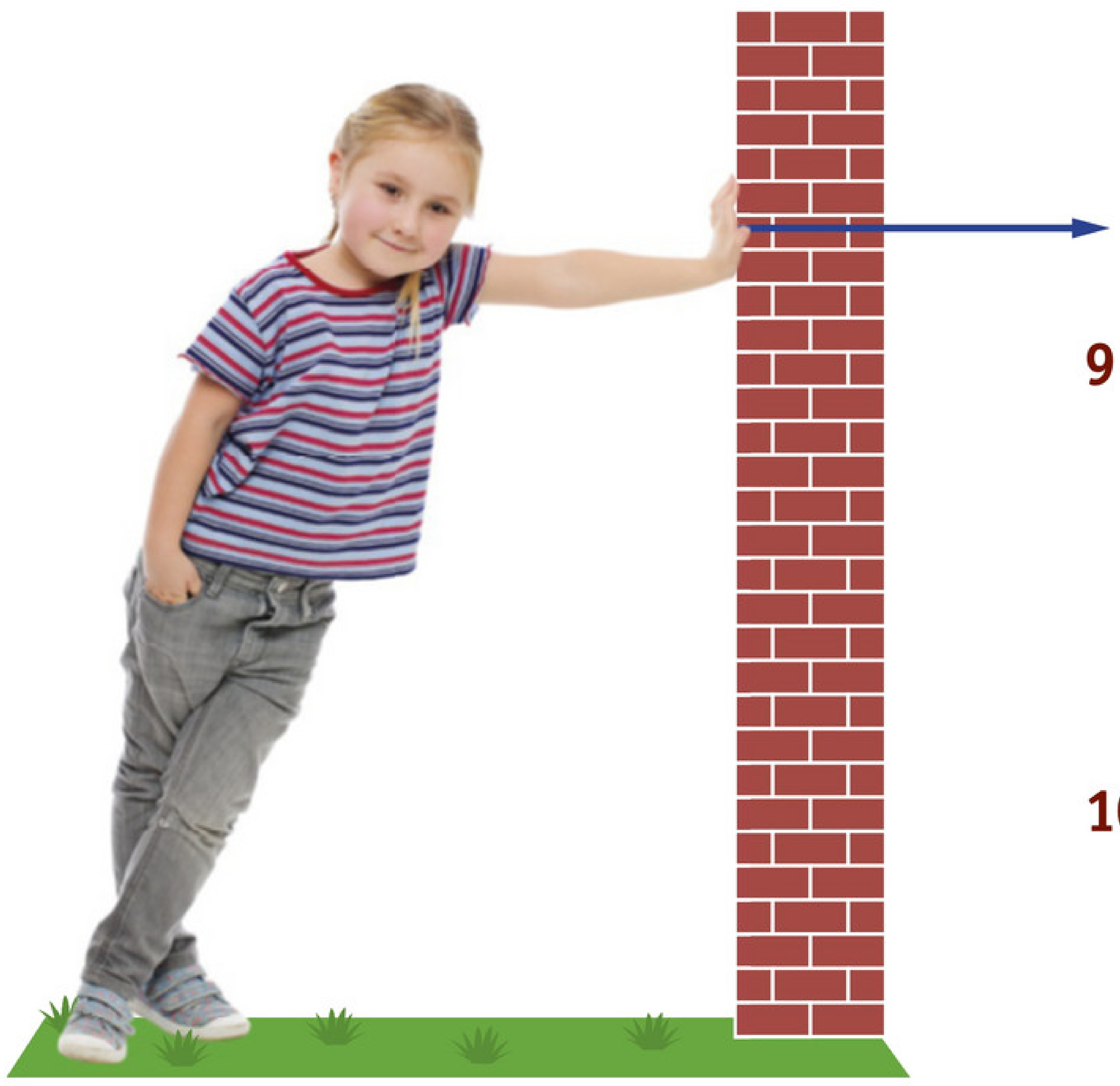
4 Look at the photos in figure 8.
How can you see that a force is being exerted or has been exerted:
a on the rubber band?
b on the vaulting pole?
c on the car?

▲ **figure 8**
What effects do forces have?

5 For each of the following situations, write down:
– whether the deformation is elastic or plastic;
– the name of the force that has caused the deformation.
a Marie flops down on a nice soft two-seater sofa.
b A dog sinks down in the freshly fallen snow.
c A plumber puts a bend in a copper tube.
d A thin branch breaks when a cat sits on it.

6 Have another look at the rubber band in figure 8a.
What is the name of the force that:
a is making the rubber band stretch a long way?
b the rubber band is exerting on the boy's hands?

7 You need worksheet 1-1 for this exercise.
Draw the following forces on the worksheet. Use a force scale of 1 cm $\triangleq$ 100 N.
a the pull of 400 N that Jake is applying to the rope
b the force of 450 N that Anthea's foot is exerting on the beam
c the force of 500 N that the Earth is exerting on Rosemary
d the two forces of 150 N that the bullworker is exerting on Pete



▲ **figure 9**
the force of the hand on the wall

8 Figure 9 shows the force that Sophie is exerting on the wall with her hand.
- **a** What force scale has the artist used if the force on the wall is 46 N?
- **b** Sophie has a mass of 30 kg. Draw the force of gravity on Sophie, using the same force scale. Calculate the length of the arrow.

9 Calculate the force due to gravity:
- **a** on a bucket of rock salt of mass 10 kg.
- **b** on a bag of dog food of mass 1.5 kg.
- **c** on a box of chocolates of mass 350 g.
- **d** on a chocolate bar of mass 45 g.

10 You need worksheet 1-2 for this exercise.
The worksheet shows you two gymnasts who are working against gravity.
- **a** Calculate the force due to gravity on Lisa and Ewan.
- **b** Draw the force due to gravity in each drawing as an arrow.
  Use a force scale of $1\ \text{cm} \mathrel{\hat{=}} 100\ \text{N}$.

Plus The centre of gravity

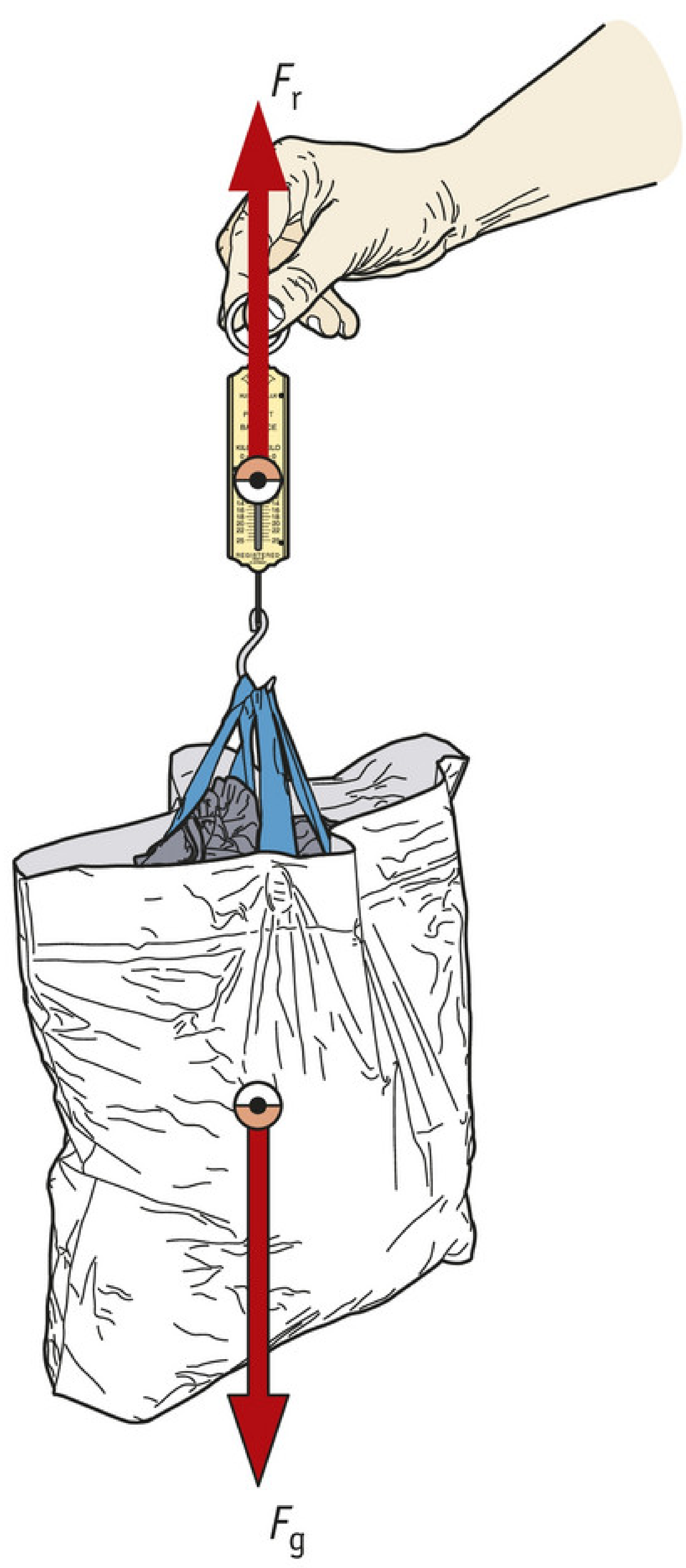
***11** Jane is standing still on one leg (figure 10).
- **a** What is the supporting plane in the situation in figure 10?
- **b** What do you therefore know about the centre of gravity of Jane's body?
- **c** Jane shifts her upper body a little bit to the right.
  Why does she then start losing her balance? Include the phrase 'centre of gravity' in your explanation.
- **d** What can Jane do to recover her balance in the new position?

***12** You need worksheet 1-3 for this exercise.
- **a** Objects a, b and c are all made of the same material.
  For each of the objects, place a C to indicate (roughly) where the centre of gravity is.
- **b** Objects d and e are made partly of iron (the dark section) and partly of aluminium (the light section).
  Indicate the centre of gravity of each object.

◀ **figure 10**
It is more difficult to keep your balance if you stand on one leg.

2 Forces in equilibrium

In a tug-of-war, the two teams can hold each other in balance for quite a long time. Even though the people are pulling as hard as they can, the rope hardly moves at all. As long as the forces to the left are the same as the forces to the right, nothing changes.



▲ **figure 11**
forces of gravity and resistance

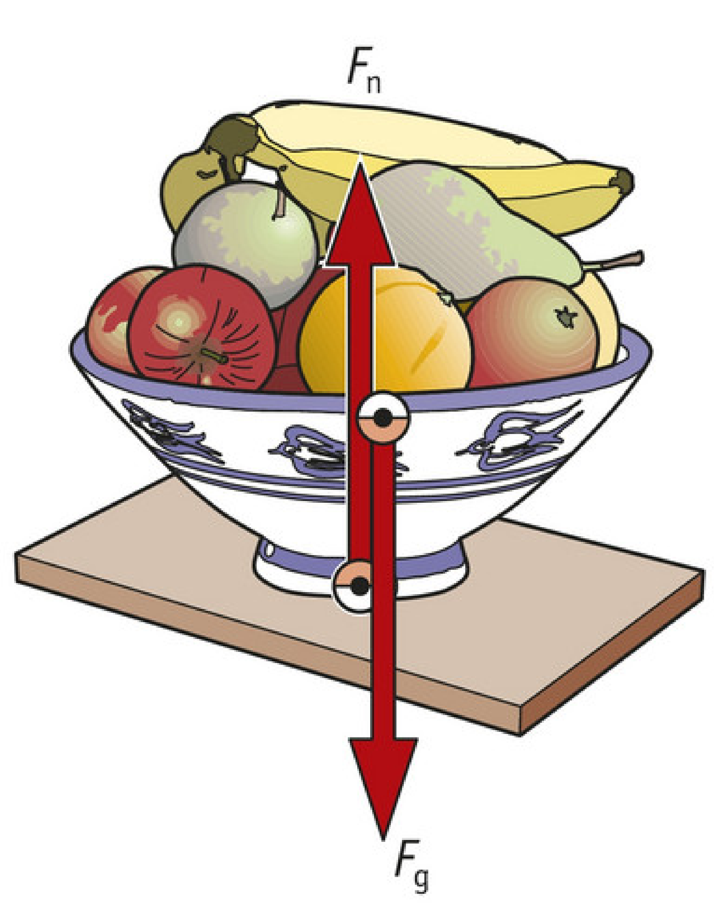
Two forces in equilibrium

Figure 11 shows you a bag of potatoes hanging on a dynamometer. There are two forces acting on the bag: the force of gravity F_g and the resistance of the spring F_r. A letter F is used in physics as the symbol for a *force*. Gravity acts downwards and the resistance of the spring acts upwards.

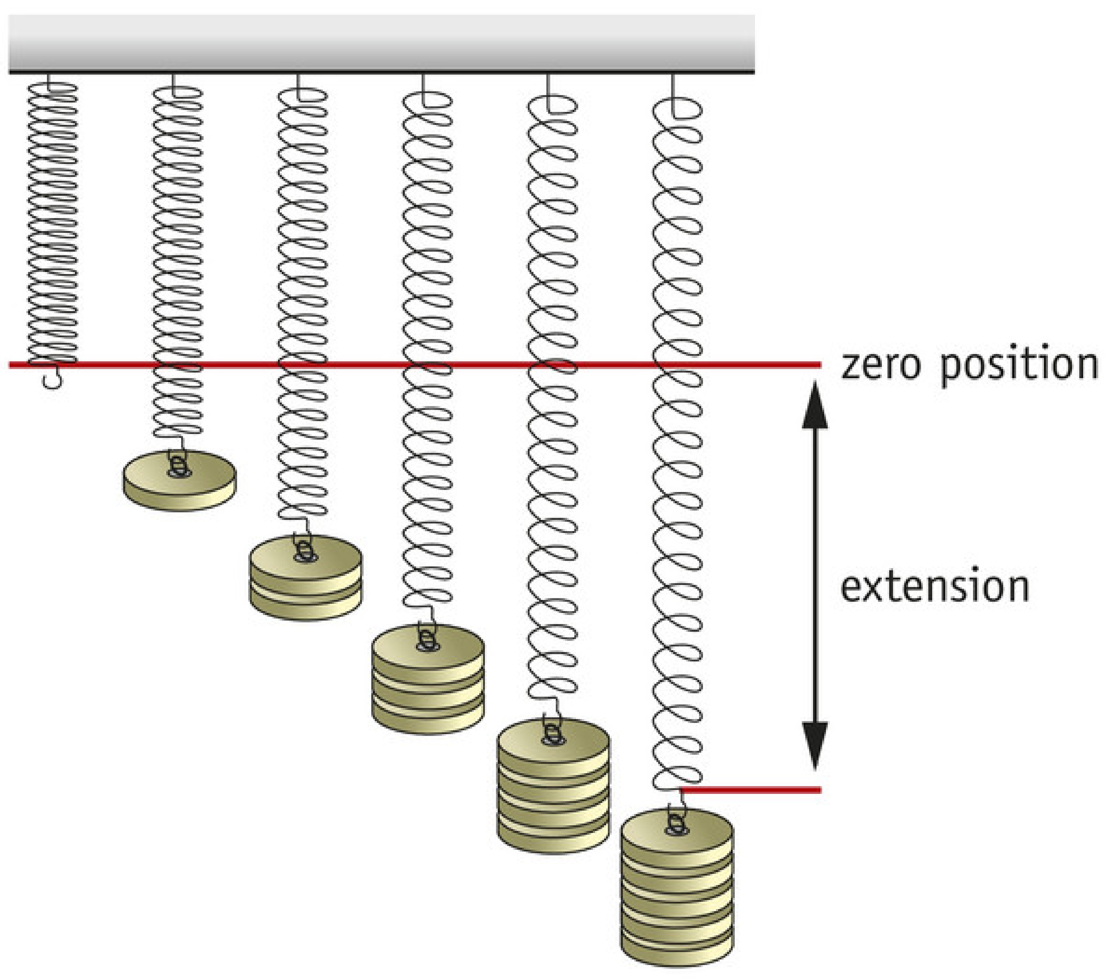
The forces in this situation are in equilibrium, i.e. balancing each other out. Both are pulling equally hard on the bag, but in opposite directions and so nothing happens. The bag does not move upwards and it does not move downwards either. The forces due to the spring and due to gravity balance each other out.

If you hang an object on a spring, it will not immediately be in equilibrium. You can also see that: the object moves downwards and the spring stretches further. As it does so, the spring's resistance increases. That continues until the resistance equals the force due to gravity. At that moment, the system is balanced.

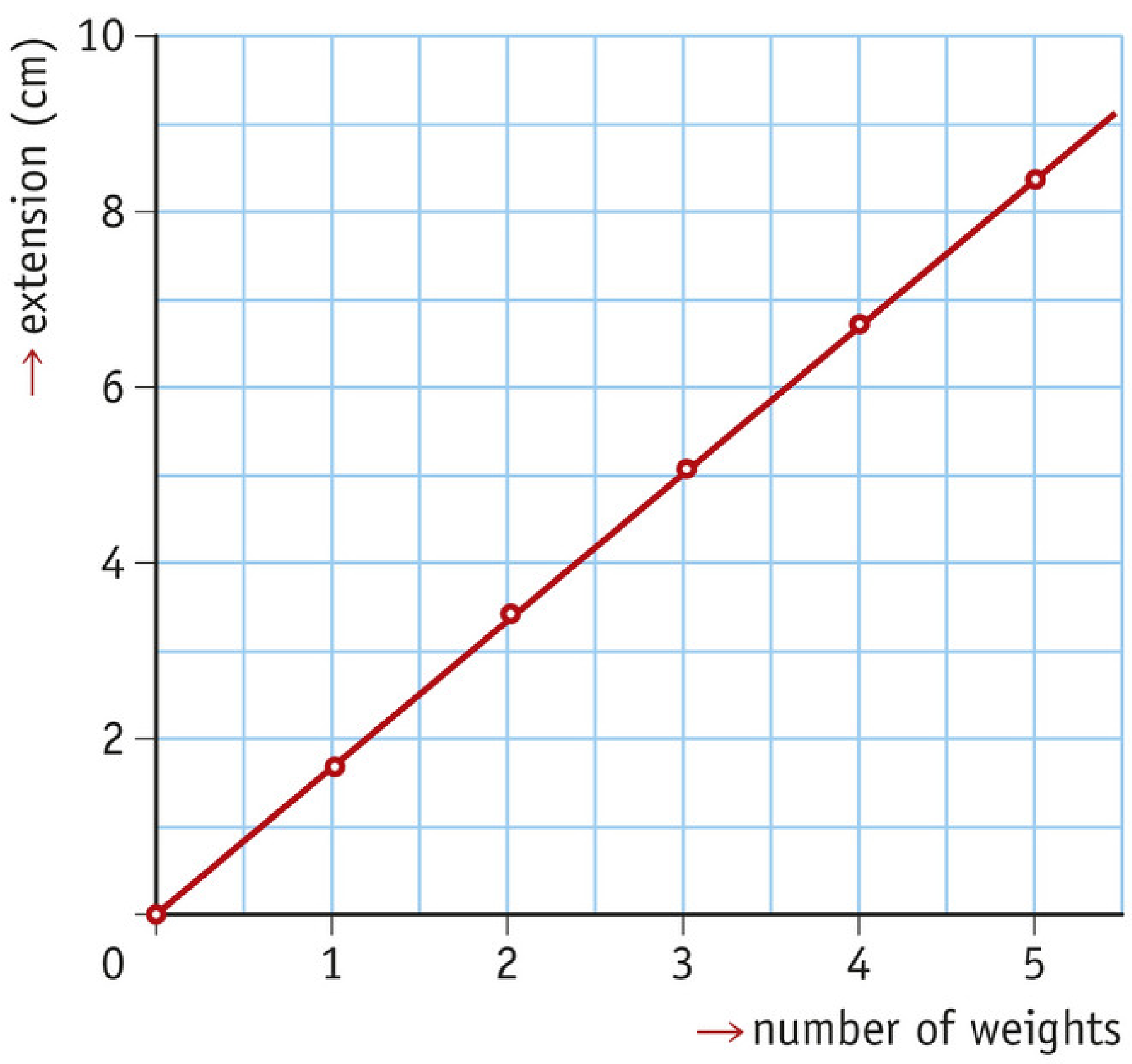
Figure 12 shows you another example of two forces that are in equilibrium. If the table top was not there, the fruit bowl would fall. That does not happen, because the top of the table exerts a force upwards, perpendicular to the table surface: the **normal force** F_n. The normal force balances the force of gravity, so that the fruit bowl does not move.



▶ **figure 12**
force of gravity and the normal force



▲ **figure 13**
experiment with a helical spring



▲ **figure 14**
the graph of the experiment with the helical spring

Force and extension Experiment 1

Figure 13 sketches out how you can determine the relationship between the force on the spring and its **extension**, the number of centimetres by which the length of the spring increases. You can do that by hanging more and more small weights on the spring and measuring its extension each time. You compare the length of the spring against the **zero position**, the length of the spring at the start of the experiment when it is not being stretched.

If you use weights with a mass of 100 g, the force increases each time by (roughly) 1.0 N. This will let you show that the extension is **directly proportional** to the force:

- If the force is 2× as large, the extension is also 2× as large.
- If the force is 3× as large, the extension is also 3× as large.
- And so forth.

If you represent the measured results as a graph, the result will be a straight line that goes through the origin (figure 14).

Because the extension of a spring is proportional to the force, you always get the same value if you divide the force by the corresponding extension. In symbols:

$$C = \frac{F}{x}$$

This constant value C is called the **spring constant**. If you give the force F in N and the extension x in cm, you get the spring constant C in N/cm. This spring constant here is a measure of the **stiffness** of a spring. For example, a spring with C = 200 N/cm is much stiffer than a spring with C = 2 N/cm.

Worked example 1

A spring is 23.2 cm long when nothing is hanging from it and 31.8 cm long when a weight of 250 g is hanging from it.
Use this data to calculate the spring constant of this spring.

data $x = 31.8 - 23.2 = 8.6$ cm
$m = 250$ g $= 0.25$ kg

required $C = ?$

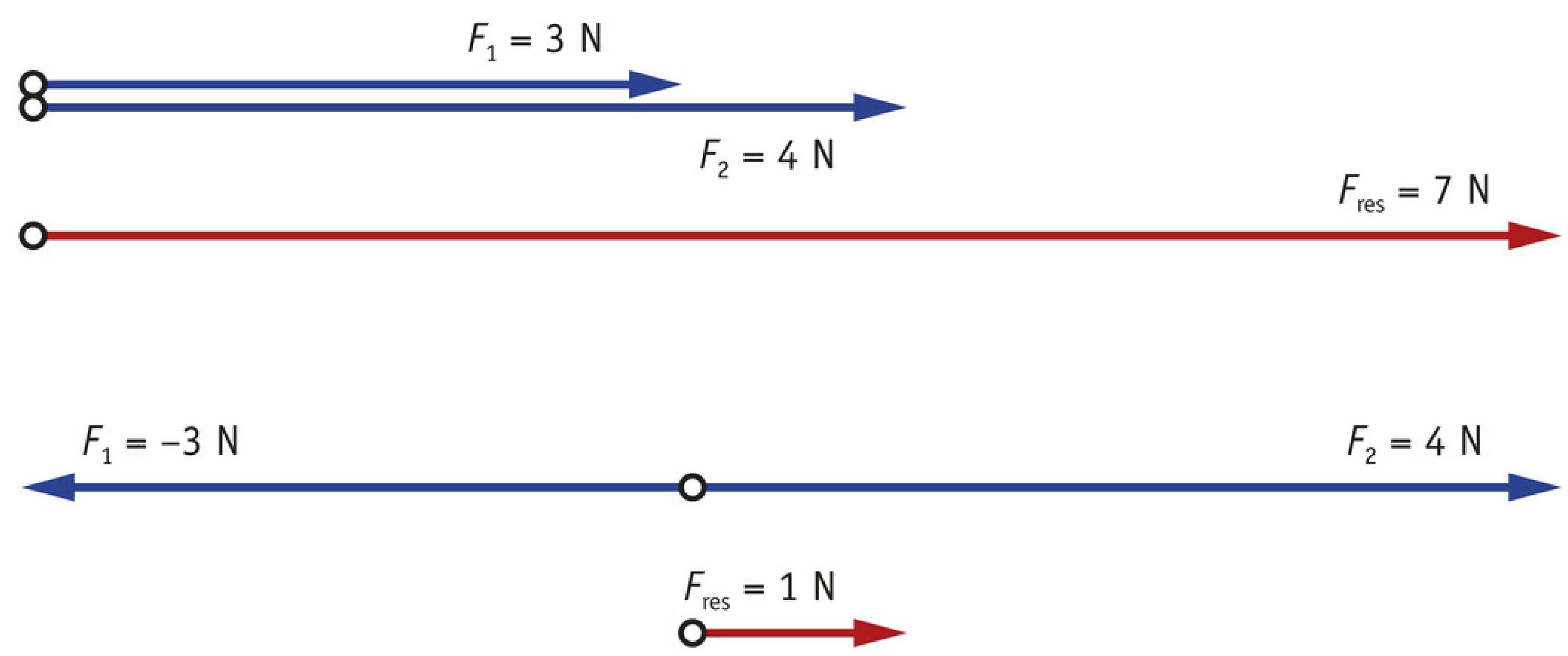
working $F_g = m \cdot g = 0.25 \times 9.8 = 2.45$ N

$$C = \frac{F}{x} = \frac{2.45}{8.6} \approx 0.28 \text{ N/cm}$$

Determining the resultant

When forces are in equilibrium, they cancel each other out: it seems as if no forces are acting on the object at all. In that case, you can say that the **resultant** force F_{res} on the object is 0 N. The resultant is the sum of all the forces added together. The resultant is also sometimes called e.g. the resultant force, net force or total force.

If the forces are acting along the same line, you can calculate the resultant by adding the forces together. When you do that, you do have to allow for the directions that the forces are acting in. You therefore have to count forces in one direction as positive numbers and forces in the opposite direction as negative numbers (figure 15). You can decide for yourself which direction you call positive.



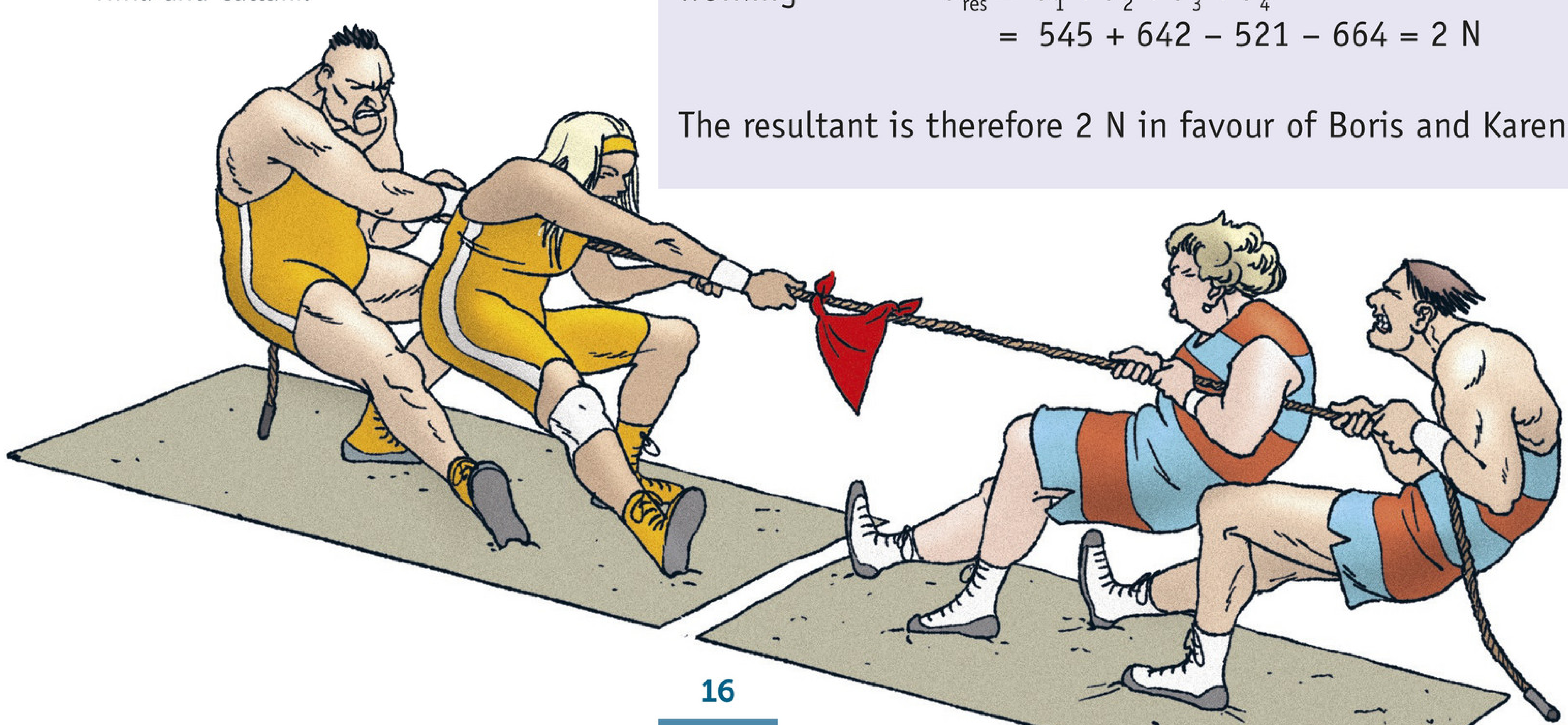
▶ **figure 15**
adding forces together

Worked example 2
Two teams are contesting a tug-of-war (figure 16). Boris and Karen are pulling to the left, one with a force of 545 N and the other with 642 N. Nina and Callum are pulling to the right, one with a force of 521 N and the other with 664 N.
Work out which team is winning.

data	F_1 = 545 N; F_2 = 642 N; F_3 = –521 N; F_4 = –664 N
required	F_{res} = ?
working	$F_{res} = F_1 + F_2 + F_3 + F_4$ $= 545 + 642 - 521 - 664 = 2$ N

The resultant is therefore 2 N in favour of Boris and Karen.

▼ **figure 16**
Boris and Karen are up against Nina and Callum.



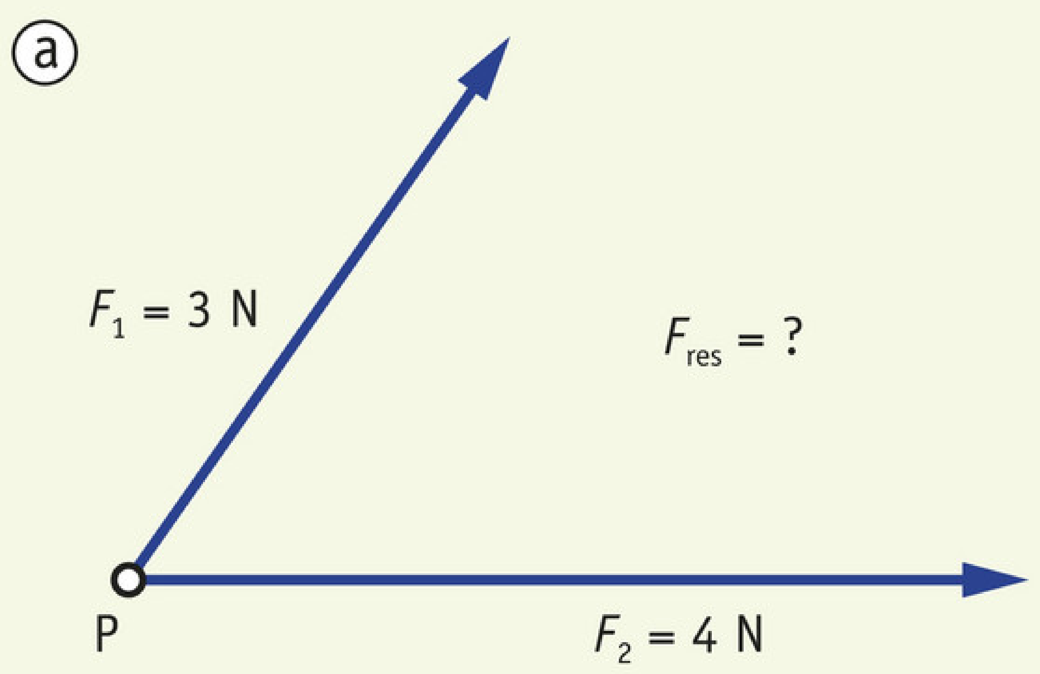
Plus Combining forces

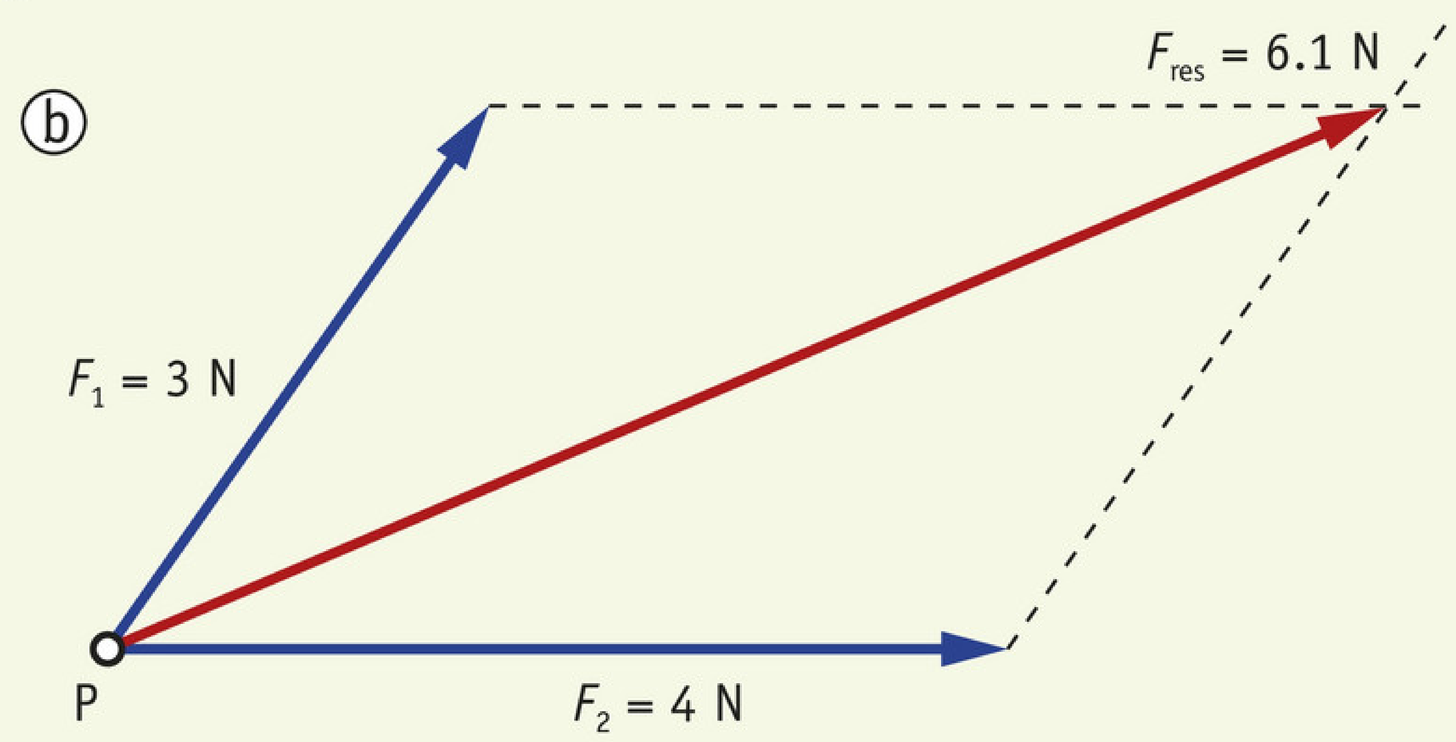
Figure 17a shows you two forces that are acting in different directions. In a case like this, there is no simple way of calculating the resultant. This is because forces are vectors. The direction matters, as well as the magnitude.

To find the resultant in this situation, the forces F_1 and F_2 have to be **combined**. You can do this by making a scale drawing (figure 17b).
It works like this:

1. Choose a suitable force scale. Draw the forces to scale, at the correct angles.
2. You can visualise the two arrows as two sides of a parallelogram. Complete the parallelogram.
3. Draw an arrow from the starting point P across to the opposite corner. This arrow gives the direction of the resultant.
4. Measure the length of the arrow. You can then use the force scale to determine the magnitude of the resultant.

▼ **figure 17**
How to determine the resultant of F_1 and F_2.





Exercises

13 Answer the questions below.

a Which three types of forces are indicated by the symbols F_n, F_r and F_g?
b What two measurement data items do you need to determine the extension?
c What formula can you use to calculate the spring constant C of a helical spring?
d You are standing on a floor. Is the normal force acting on you or on the floor?

14 Copy table 1 and fill in the missing data.

▼ **table 1** various variables and their units

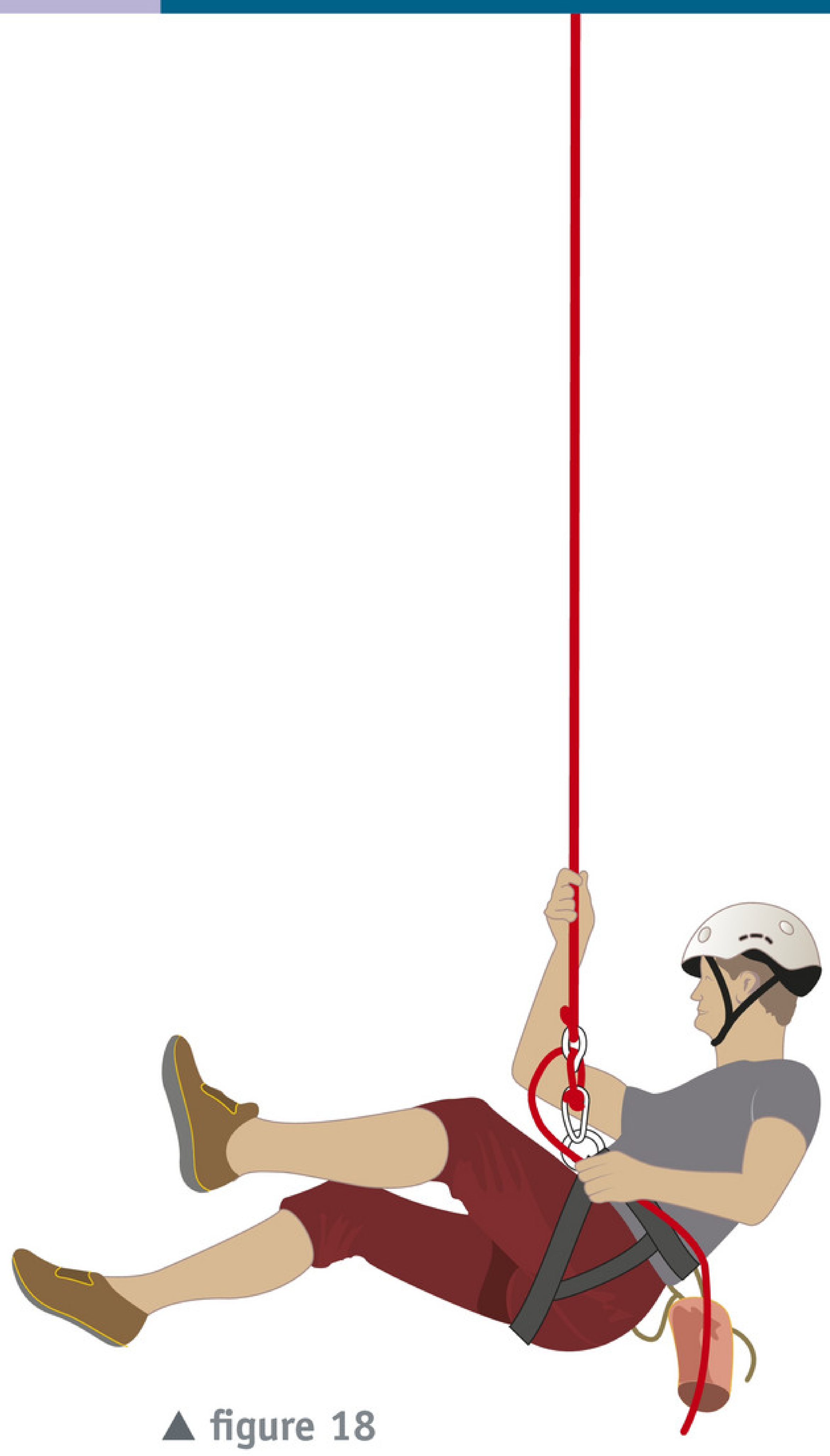
variable	symbol	unit	symbol
			N
extension			
	C		

15 Two forces F_1 = 3 N and F_2 = 4 N are acting along the same line.
How large is the resultant of F_1 and F_2:

a if they are acting in the same direction?
b if they are acting in opposite directions?

16 A mountaineer is taking a breather while abseiling (figure 18).

a Which two forces are acting on the mountaineer?
b Sketch the situation. In your sketch, you should indicate:
- the points of application of the two forces.
- the directions the two forces are acting in.
- the line along which the forces are acting.



▲ **figure 18**
a mountaineer

17 You need worksheet 1-4 for this exercise.
William is carrying out the experiment shown on the worksheet.

a Some of the results he has measured are shown in table 2.
Complete the table on the worksheet.
b See 'Skills 7' at the back of the book.
Draw the graph for this experiment on the worksheet.
c Use the graph to determine:
- how far the spring would be stretched by a force of 0.5 N.
- how far the spring would be stretched by a force of 0.9 N.

d Explain why the result from 0.5 N is more reliable than that for 0.9 N.

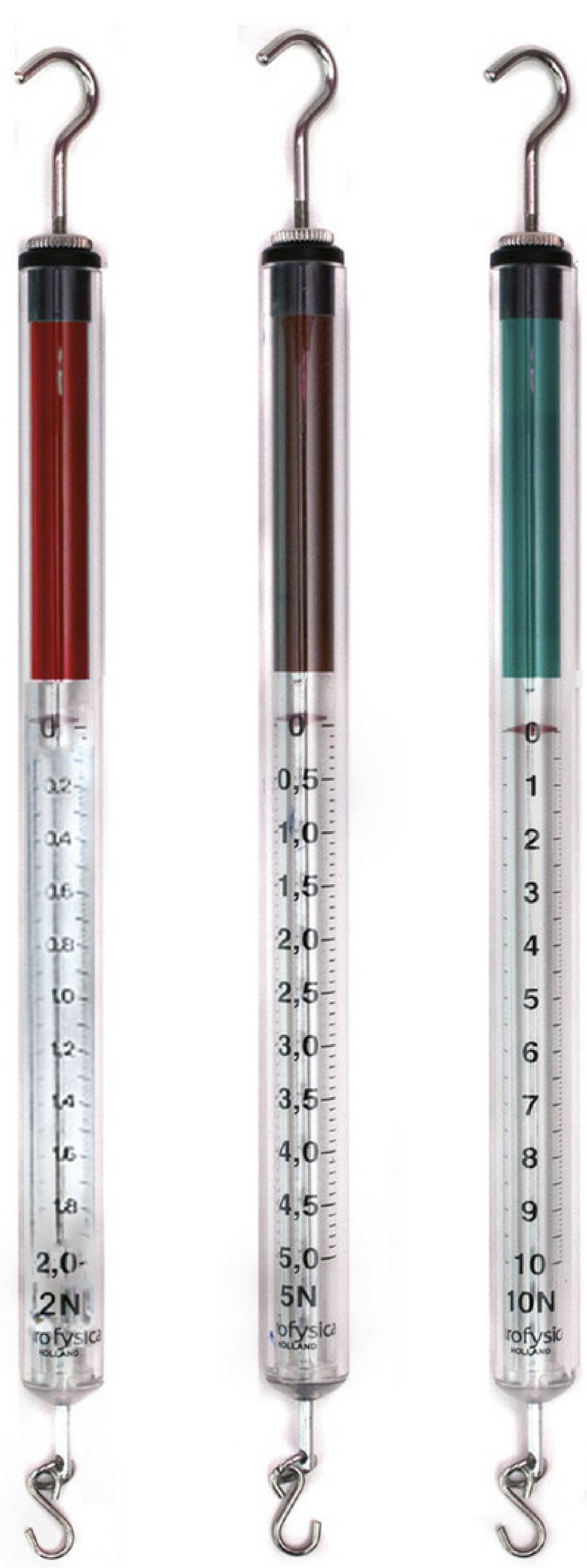
▼ **table 2** William's measured results

number of weights	force on the spring (N)	extension (cm)
0	0	0
1	0.15	1.8
2	0.30	
and so forth		

18 Figure 19 shows you three dynamometers that are all the same size: red (range 0 to 2 N), brown (0 to 5 N) and green (0 to 10 N). The distance between the zero point and the end point of the scale for each dynamometer is 8.4 cm.

a Which dynamometer has the stiffest spring? What tells you that, without you having to determine the spring constant first?
b See 'Skills 5' at the back of the book.
Calculate the spring constant of the spring in the red dynamometer.
c Work out what the spring constants in the other dynamometers must be (without using the formula).

If you need more practice, go to the V-trainer.



◀ **figure 19**
three dynamometers

▲ figure 20
a bungee jumper

***19** Ellen is doing an experiment with a helical spring (C = 35 N/m). First, she measures the length of the spring with nothing hanging on it: 22 cm. Then she hangs a block of mass 250 g on the spring.
Calculate how long the spring will get. Show all your calculation steps clearly.

20 Figure 20 shows you Tony bungee-jumping.
- **a** In the situation in the photograph, the bungee (the elastic rope) is not yet resisting Tony's fall.
  How can you see that?
- **b** When does the resistance of the bungee start acting on Tony?
- **c** At a certain point, Tony will feel that the resistance of the elastic rope has become greater than the force of gravity.
  How will he notice this?
- **d** When is the resisting force exerted on Tony at its greatest?
- **e** In what direction is the resultant acting on Tony at that point in time?
- **f** So what happens to Tony then?

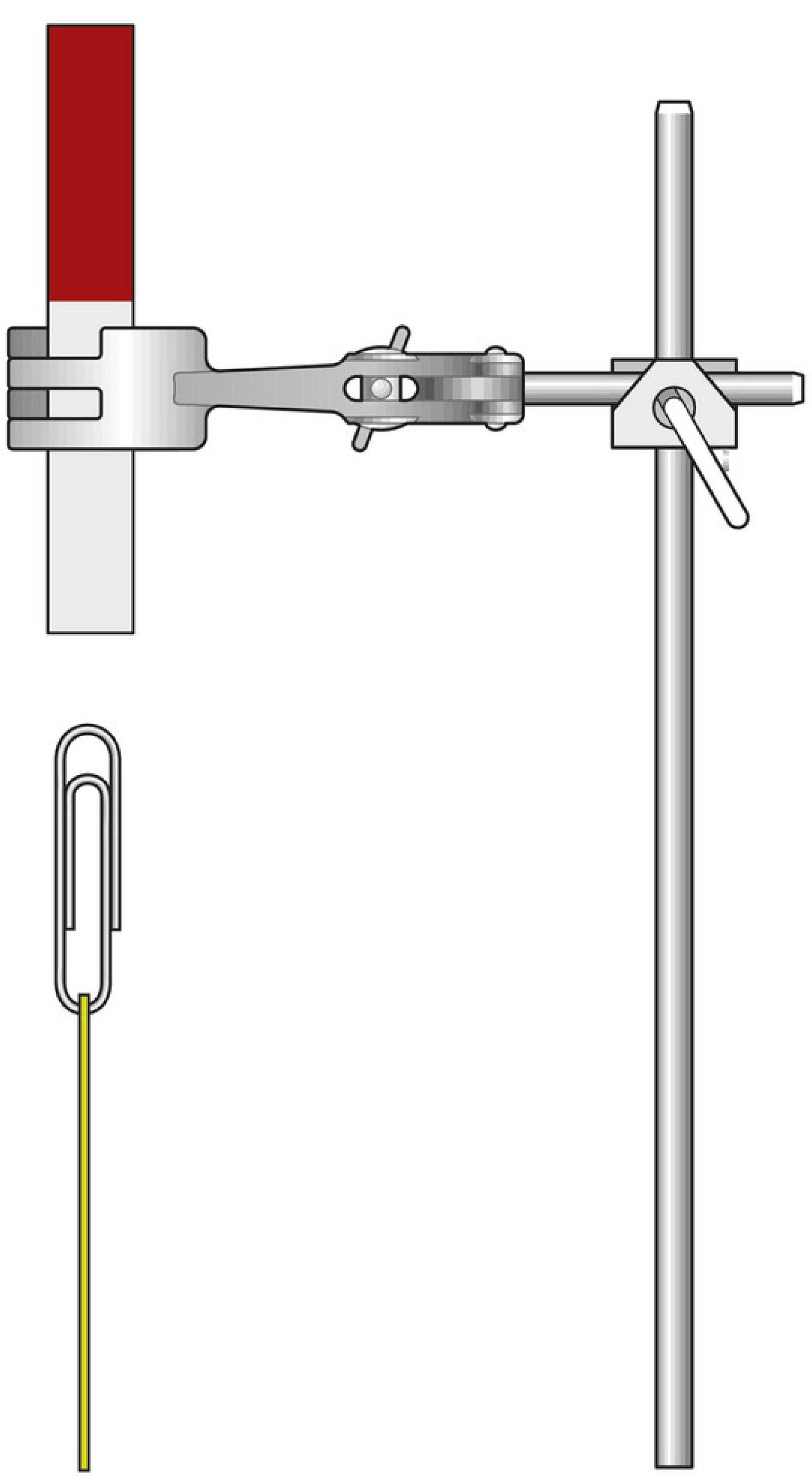
***21** Figure 21 shows you how you can make a paperclip 'float' using a magnet. There are three forces acting on the paperclip.
- **a** Which two forces are acting downwards?
- **b** Which force on the paperclip is acting upwards?
- **c** Which of the three forces is greatest? How can you tell that?

Plus Combining forces

22 You need worksheet 1-5 for this exercise.
The worksheet shows you five drawings labelled a to e in which two forces F_1 and F_2 are acting at the same point.
- **a** For each of the five drawings, add in the resultant of F_1 and F_2.
- **b** Make a table and fill in the following for each drawing:
  - how long the arrow is for each of the resultants.
  - how big the resultant force is, according to the force scale.

23 You need worksheet 1-6 for this exercise.
The worksheet has a sketch showing how tugboats A and B are pulling a cargo freighter forward. Each tug is exerting a force of 600 kN on the freighter.
- **a** Draw these forces to scale on the worksheet.
- **b** Draw the resultant of these two forces.
- **c** Determine the magnitude of the resultant.

24 Two forces F_1 = 3 N and F_2 = 4 N are acting on the same object. The angle between F_1 and F_2 is 35°.
Use a drawing to determine the magnitude of the resultant.



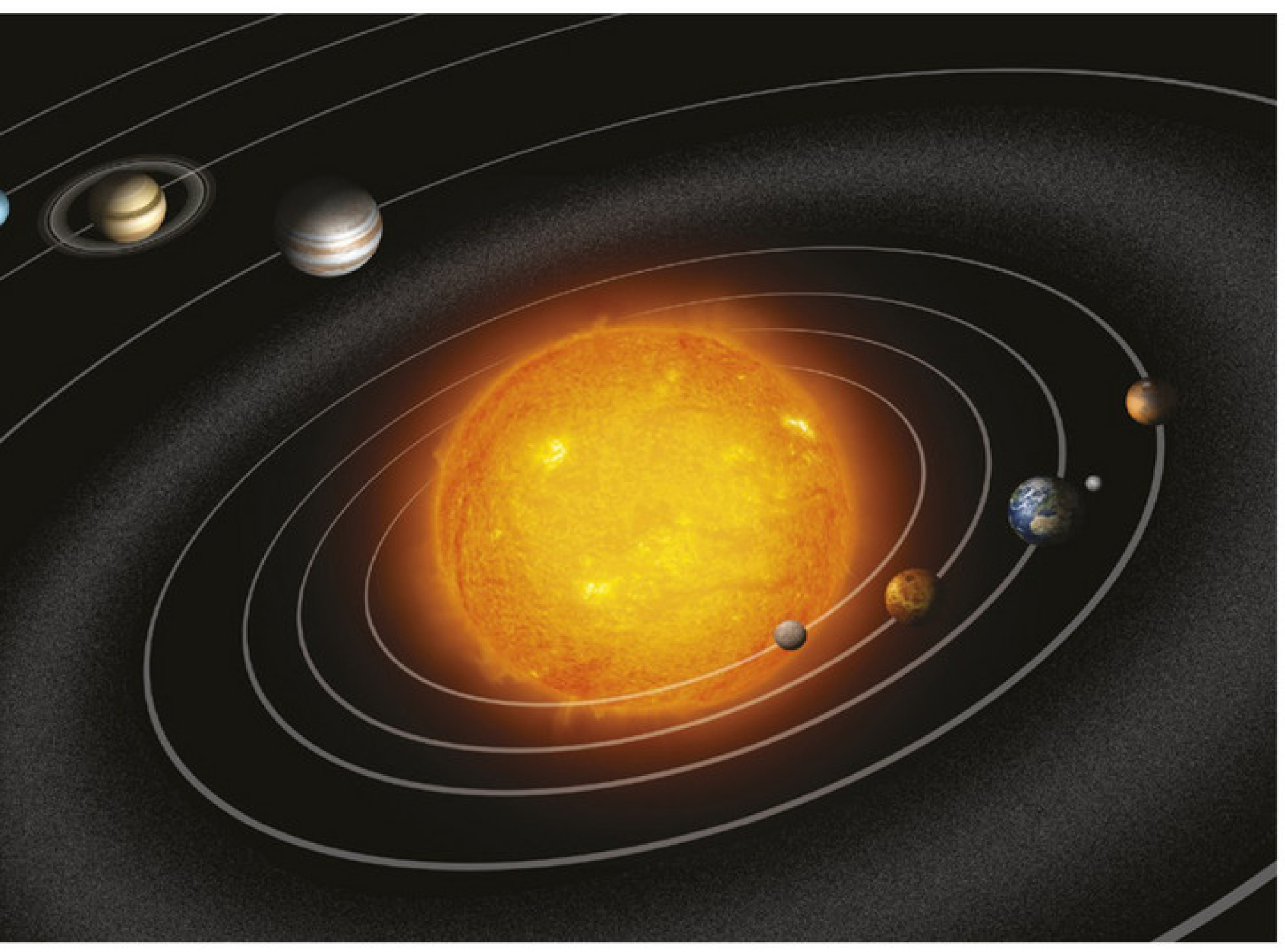
◀ figure 21
the floating paperclip

3 Forces in the universe

For a long time, scientists thought that gravity was something that only applied close to the Earth. They believed that stars and planets were located in the 'heavenly spheres', far beyond the influence of gravity. That idea turned out to be wrong. Gravity is present throughout the universe and it determines how stars, planets and moons move.

The solar system

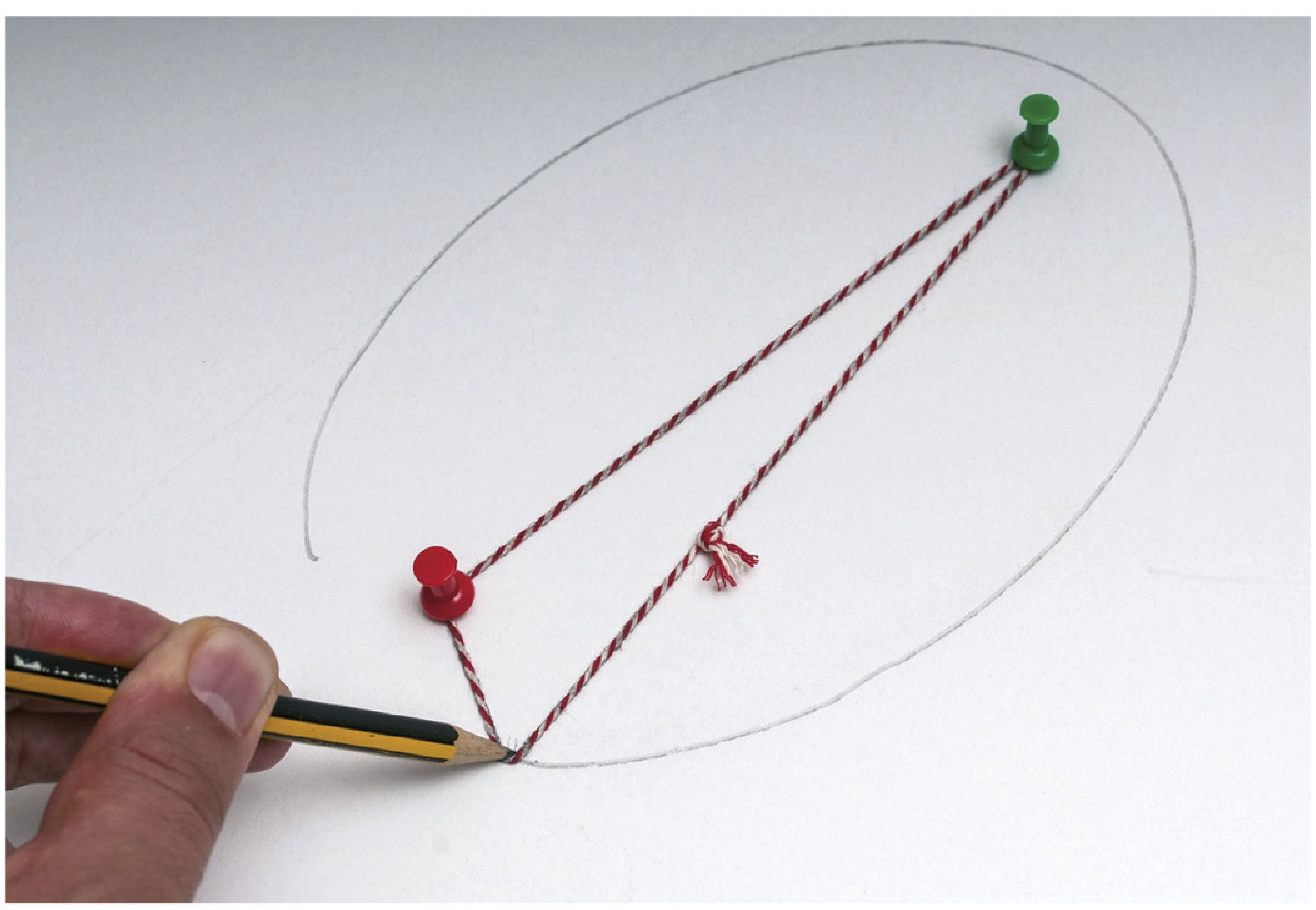
The Earth is one of the planets in the solar system (figure 22). Like Mercury, Venus and Mars, Earth is one of the terrestrial planets. These planets are relatively small and have rocky surfaces. The gas giants Jupiter, Saturn, Uranus and Neptune are much larger. They consist largely of gasses and do not have a surface that you could walk on.



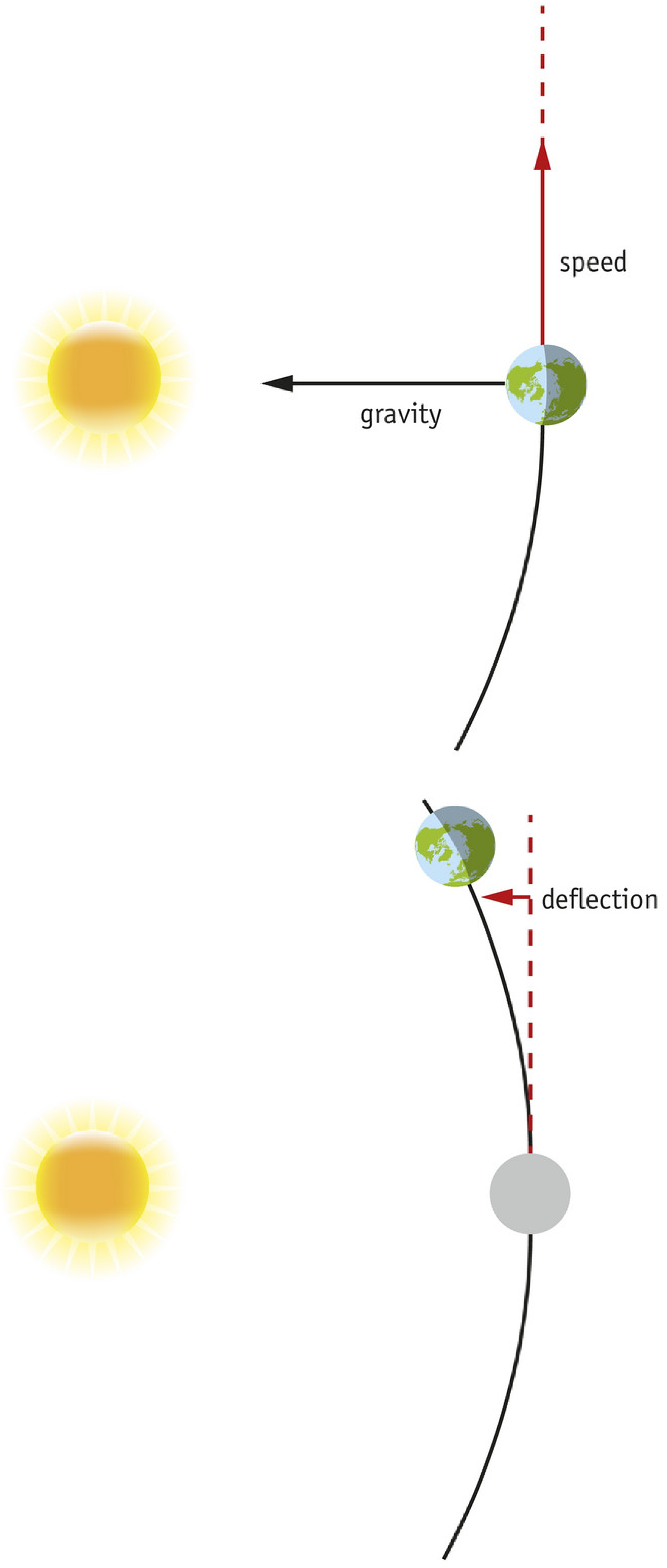
▲ figure 22
the solar system (not to scale)

The distances in the solar system are enormous. In comparison, the planets are very small. The Earth is 150 million km away from the Sun on average, whereas the Earth's diameter is only roughly 13 thousand km. The solar system in figure 22 has therefore not been drawn to scale, otherwise you would not be able to see the planets at all and even the Sun would be no more than a dot.

The planets go around the Sun in elliptical orbits. An ellipse is a geometric shape that looks like a squashed circle. Figure 23 shows you how you can draw an ellipse using two drawing pins, a piece of string and a pencil. As you put the drawing pins closer together the more the ellipse approximates a circle. The ellipses of the planets' orbits are almost circular.



▶ figure 23
How to draw an ellipse.



▲ figure 24
the effect of gravity on the motion of a planet

The motions of the planets

The English physicist Sir Isaac Newton wondered what held a planet in its orbit around the Sun. Why does the planet not keep moving in the same direction, like a marble rolling along a smooth flat table? After all, the marble does not travel in a big curve and come back to you. So why does a planet have an elliptical orbit around the Sun?

Newton came to the conclusion that gravity plays an important role in this. In the same way as an apple is attracted to the Earth, a planet is attracted to the Sun. The reason why a planet does not fall into the Sun is because it is moving at high speed past the Sun. Gravity and the planet's own motion combine to keep the planet in orbit around the Sun.

Figure 24 shows you how this works. As you can see, gravity acts perpendicularly (or almost so) to the direction of motion of the planet. This means that the planet does not move in a straight line, but instead bends in the direction gravity is pulling, and that effect is present all the time. Gravity pulls continually on the planet, so that it ultimately travels in a complete ellipse around the Sun.

In any form of circular motion, there is a **centripetal force** that keeps making the object deviate. In the solar system, the Sun is the central point and gravity is the centripetal force. Figure 25 shows you another situation in which an object is rotating. In this case, it is a force provided by the muscles that keeps the ball constantly changing direction.

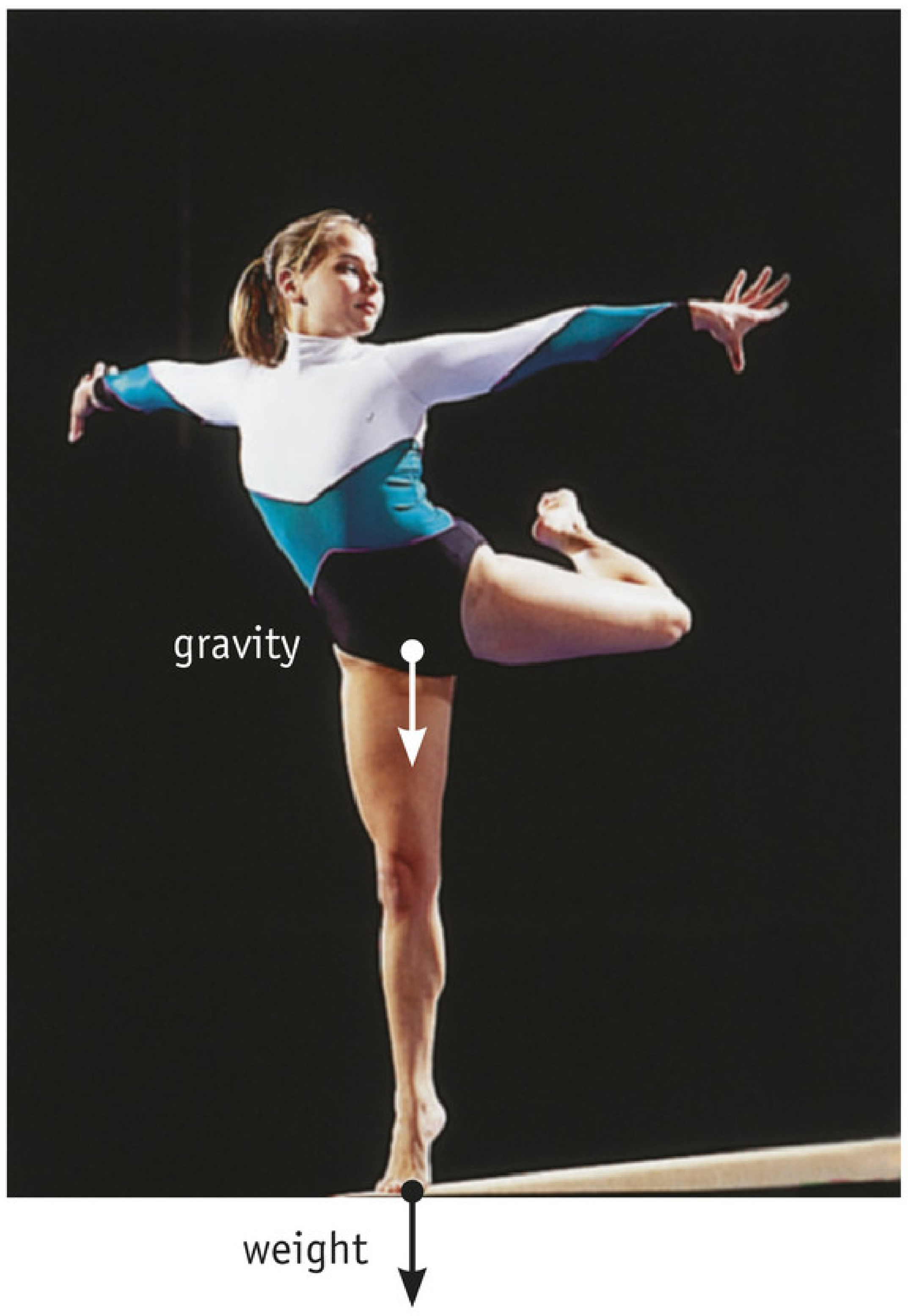
Gravity and weight

Because objects are attracted by the Earth, they themselves can exert forces. You notice this if you lift something, for instance a crate of soft drinks. Gravity is pulling on the crate and therefore the crate pushes against your hands. If you do not put the crate down quickly again, the imprint will remain on your hands.

The force that the crate exerts on your hands is called its **weight** (*W*). The force of gravity acts on the object and there is a reaction, equal to the weight but acting in the opposite direction, of your hands on the crate. It is because of this reaction that you feel the weight of the crate.

The weight of the crate is not the same as its mass. Mass is the measure of the 'amount' of substance of which the object is made, measured in kilograms. The mass has only a magnitude and does not have a direction, unlike a weight. Mass is also constant, its value does not depend on the strength of the gravitational field at that point. If the mass of the crate on the Earth's surface was 10 kg then it would still be 10 kg on the surface of the Moon where the strength of the gravitational field is much less.

◀ figure 25
A lot of strength is required to keep changing the direction that the ball is moving in.



▲ **figure 26**
Gravity is acting on the girl. Her weight is acting on the beam.

The weight of an object of mass m is the force of gravity exerted by the Earth on the object. Expressed as a formula:

$$W = F_g = m \cdot g$$

where g is the strength of the gravitational field at that point (about 9.8 N/kg at the surface of the Earth). The weight of an object in the Earth's gravitational field does not change, it is the same whether the object is falling or at rest on the surface of the Earth.

Worked example 3
The gymnast in figure 26 has a mass of 52 kg.
Calculate the weight that her foot is exerting on the beam.

data	$m = 52$ kg $g = 9.8$ N/kg
required	$W = ?$
working	$W = F_g = m \cdot g = 52 \times 9.8 \approx 510$ N

Weightlessness

We are only really conscious of our own weight because of the reaction of the ground on our bodies. If we removed the ground then there would be no reaction, we would accelerate downwards due to the gravitational attraction at that place, and we would therefore feel **weightless**. We still have a weight as there is still a gravitational force acting on us, it is just that we do not feel that weight.

When you jump, your body is in **freefall** for a short time. During that time the only force acting on your body is gravity. For a moment, because your body is not supported by anything, you have the **sensation of weightlessness**.

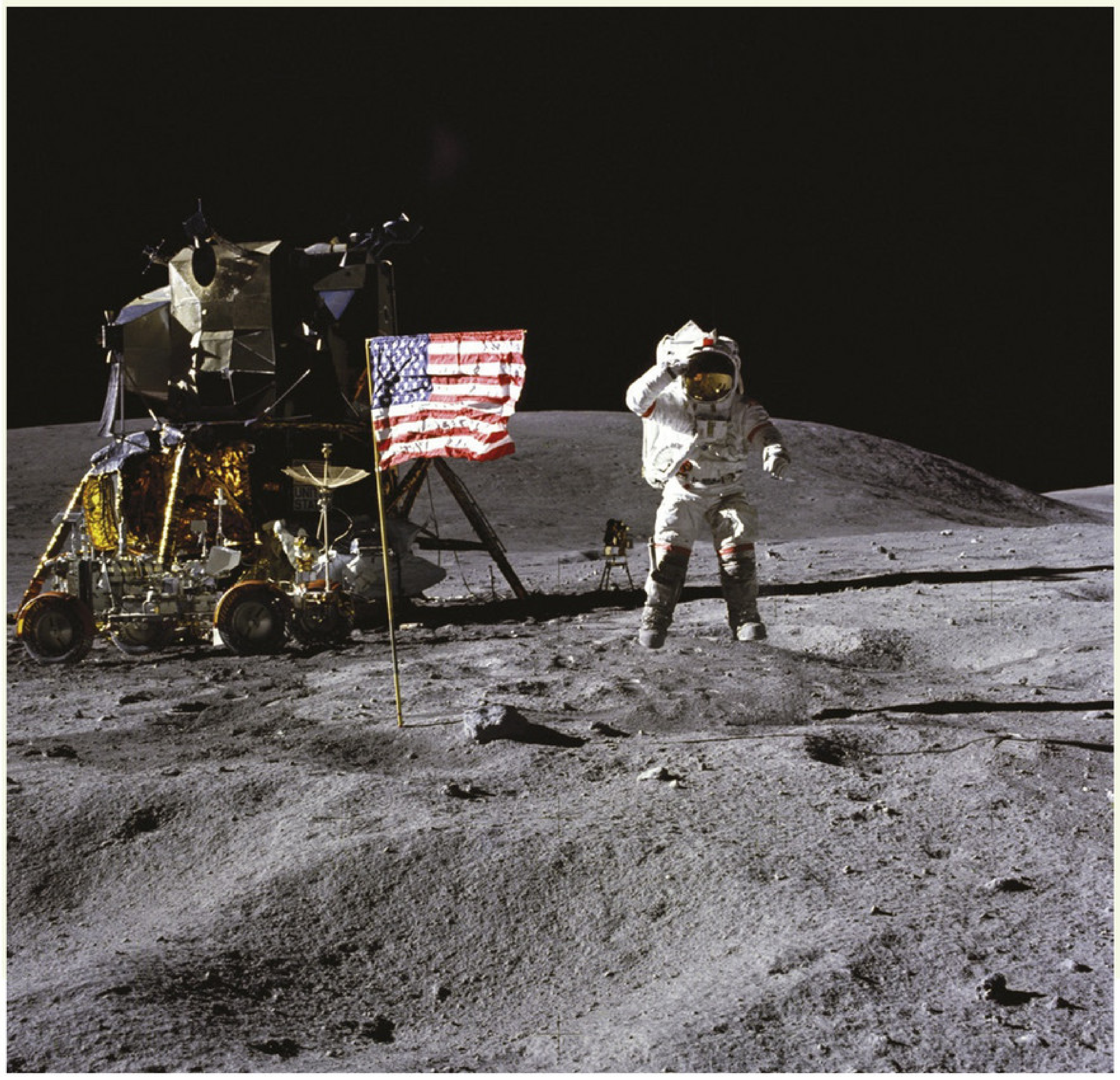
A spaceship that is orbiting the Earth is permanently in freefall and so the only force acting on the spaceship is the force due to gravity. The astronauts in the spaceship move in exactly the same path as the spaceship, they are also moving in freefall and so they feel no reaction between the spacecraft and their bodies and so feel weightless. Unlike mass the apparent weight does change with the gravitational field. The crate mentioned earlier would have an apparent weight of 98.1 N on the Earth's surface, 16 N on the Moon's surface and 0 N in freefall.

Plus The strength of gravity

The force of gravity on an object is roughly the same at all points on the Earth's surface. It actually does vary a little and is not quite the same at the equator as it is at the poles. You can check that by hanging a brick weighing 1.0 kg from a dynamometer. The dynamometer will always show you that the force is 9.8 N, wherever you are on the Earth. The Netherlands, Australia, America or Japan – it makes no difference: *g* is 9.8 N/kg everywhere.

If you were to do this experiment on the Moon, though, you would get a different result. The dynamometer would then register only 1.6 N when a brick of mass 1 kg is hanging from it. The value of *g* on the Moon is 1.6 N/kg, roughly 1/6 of the value it has on the Earth. If you were to measure *g* on different planets, then you would get different values (table 3).

You can see that *g* on the Moon is much less than on the Earth from the video recordings that were made on the Moon (figure 27). The astronauts are able to jump very high on the Moon, much higher than on Earth. If they jump off a rock, they also land much more softly. It looks almost as if they are moving in slow motion.



▼ **table 3** the strength of gravity on various bodies in the solar system

body	value of *g* (N/kg)
Earth	9.8
Moon	1.6
Mars	3.7
Mercury	3.7
Titan	1.4
Venus	8.9

◀ **figure 27**
an astronaut jumping on the Moon in April 1972

Exercises

25 Answer the questions below.
- **a** Why doesn't a planet fall in a straight line towards the Sun?
- **b** What is the centripetal force that holds the planets in their orbits?
- **c** What do you call the force that an object exerts upon its support?
- **d** Under what circumstances do people feel weightless?

26 Martin is going to make a model of the solar system. He wants to use a marble with a diameter of 1.3 cm for the Earth.
- **a** What is the diameter of the Earth in reality?
- **b** What scale will Martin therefore be using for his model?
- **c** The diameter of the Sun is in reality 1.4 million km. What would be the diameter of the Sun in Martin's model?

27 Continuation of exercise 26.
Astronomers often express distances in astronomical units (AU). One astronomical unit is equal to the average distance between the Earth and the Sun.
- **a** How far is 1 AU in kilometres (roughly)?
- **b** How far is 1 AU in Martin's model?
- **c** Neptune, the eighth and most distant of the planets, is an average of 4.5 billion km from the Sun. Express this distance in AU.
- **d** For even larger distances, astronomers use a unit called a light-year (the distance light travels in one year). Look up the speed of light and work out how many kilometres one light-year is.

Toasted planet

One of the planets that has been discovered outside our solar system gets so close to its sun that it warms up by as much as 700 degrees Celsius in a couple of hours. The planet – a gas giant with the creative name of HD 80606b – is located about two hundred light-years away from the Earth. It is about four times heavier than Jupiter and orbits its sun in 111 Earth days. The orbit of this planet is elliptical, with the star at one end of the ellipse. At some moments the planet is as far away from its sun as the Earth is, but at others it is only one thirtieth that distance.

Source: www.wetenschap24.nl/nieuws/artikelen/2009/januari/Geroosterde-planeet.htm

28 Exoplanets are planets that have orbits around a star other than our Sun. Hundreds of exoplanets have been discovered over recent years. Some of these planets have highly elliptical orbits (figure 28).
- **a** Sketch what the orbit of the exoplanet HD 80606b looks like.
- **b** How is this orbit different from the planetary orbits in our solar system?
- **c** Why is it a good thing that the Earth does not have an orbit like HD 80606b?

***29** Satellites go around the Earth in the same way as the planets around the Sun. A satellite in a 'low Earth orbit' (LEO) goes around at an altitude of 160 km to 2000 km above the Earth's surface. It is slowed down to some extent by the extremely rarefied atmosphere at those attitudes.
Explain:
- **a** how the satellite's orbit changes if it starts to lose speed.
- **b** whether it will be slowed down more, the same amount or less in its new orbit.
- **c** what will be the ultimate fate of the satellite once its fuel is used up.

30 Use the Internet to find a video of an athlete throwing the hammer.
- **a** Describe how the ball moves before the athlete lets go of the handle.
- **b** Describe the movement after the athlete has let go of the handle.
- **c** Explain the difference. Use the term 'centripetal force'.

◀ **figure 28**
an exoplanet with an exotic orbit

▲ **figure 29**
digital scales

***31** You can buy digital scales that you can set to display the mass in kilograms or the weight in newtons (figure 29).
Explain:
- **a** how you can see that digital scales like these are actually a dynamometer.
- **b** how it is possible for the device to use the measurement results to determine the mass.
- **c** what would go wrong if you are tempted to use this device on a different planet or a moon.

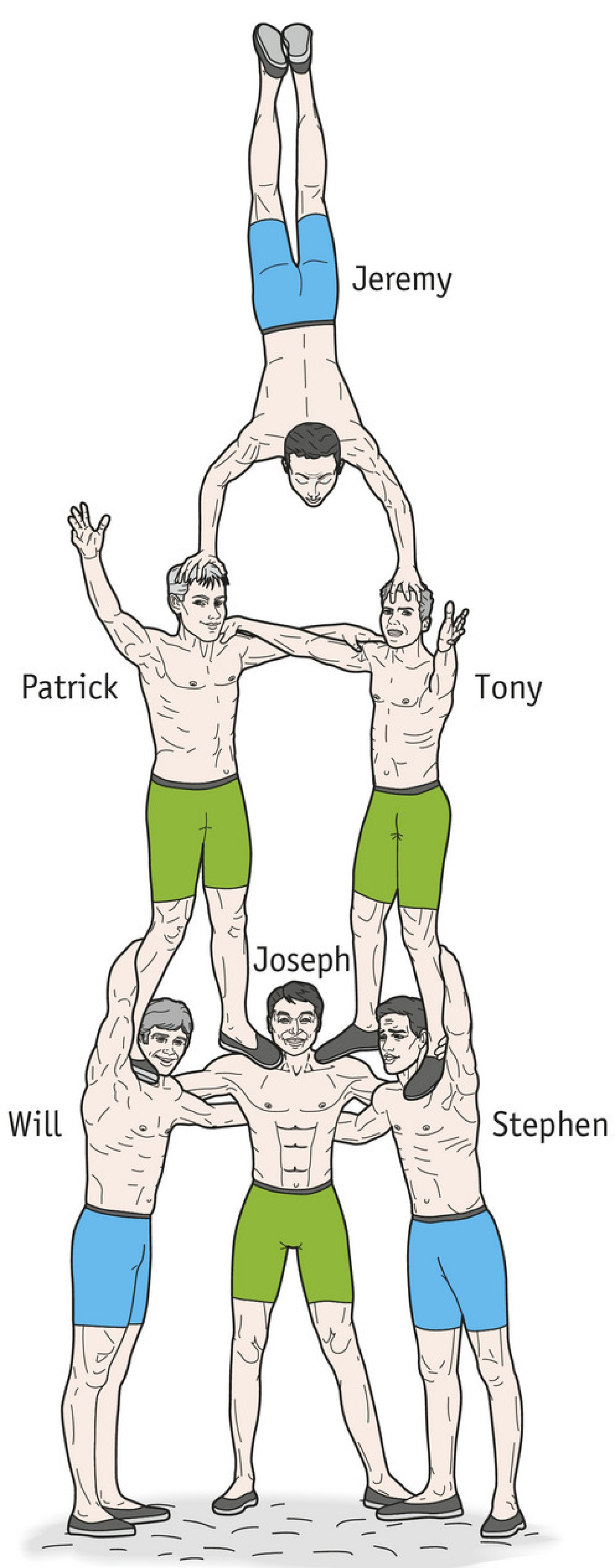
32 Six circus acrobats are performing their act. At the moment shown in figure 30, Jeremy (70 kg) is perfectly balanced.
- **a** Which three forces are acting on his body at that moment?
- **b** What is the term for the force that Jeremy is exerting on Patrick's head?
- **c** Approximately how large is that force? Explain your reasoning.
- **d** A short while later, Jeremy jumps down with a double somersault. Explain whether this:
  - changes the force of gravity on his body.
  - changes the weight of his body.

***33** The world weightlifting record of 263 kg has been held by the Iranian Hossein Rezazadeh since 2004.
Gravity in North Friesland (g = 9.8134 N/kg) is slightly higher than in South Limburg (g = 9.8112 N/kg).
Calculate the advantage that a weightlifter in South Limburg would have when lifting a barbell of 263 kg.

Plus The strength of gravity

34 An astronaut who is on the Moon picks up a rock. It does not require much of an effort: only 64 N. Later on, he takes the rock with him back to Earth. He notices that it takes a lot more effort to lift the rock on Earth.
Calculate:
- **a** the mass of the rock.
- **b** the force of gravity on the rock, when it is on the Earth.

***35** On 21 July 1969, Neil Armstrong became the first human to walk on the Moon. The mass of his body plus his space suit came to a total of 160 kg.
- **a** Calculate the weight that Neil Armstrong exerted on the Moon's surface.
- **b** Work out when Armstrong's weight was greater: with his space suit on the Moon, or without it on Earth?



◀ **figure 30**
a circus act

4 Levers

Something that you are unable to do with your bare hands may often be perfectly possible with the help of a lever. This is why all kinds of levers are used in daily life, such as door handles, bottle openers, pliers and nutcrackers.

Working with levers

You use your muscular strength every day to unscrew things or open them or lift them. You can often do that without any assistance. But it is also often the case that your muscles aren't strong enough. In that case you will use some kind of tool. It helps you exert a greater force.

A spanner is a good example of such a tool. With a spanner, you can loosen a nut that is screwed firmly in place – much too tightly for you to undo it with your fingers. You are then using the spanner as a **lever**. Like every lever, the spanner needs a **fulcrum** to rotate around. In figure 31, that fulcrum is the centre of the nut.

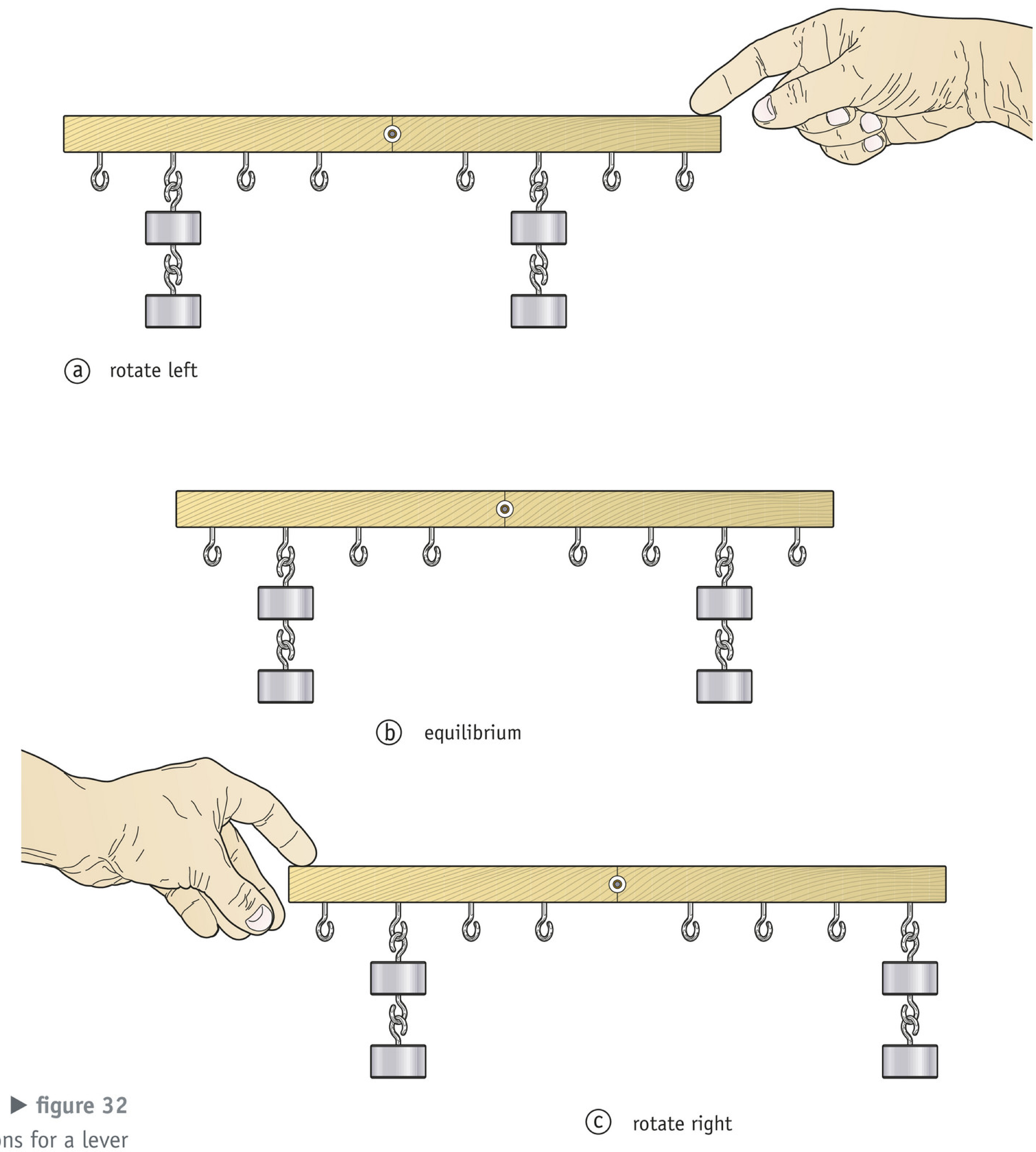
▶ **figure 31**
A spanner lets you loosen the nut easily.

In this situation, two forces are involved. The strength of your muscles is applied at the end of the spanner, a long way from the fulcrum, and this makes the spanner apply a force on the nut, closer to the fulcrum. The force acting on the nut is much greater than the strength of your muscles, and you notice that you can easily use the spanner to loosen the nut.

The moment of a force Experiments 2 and 3

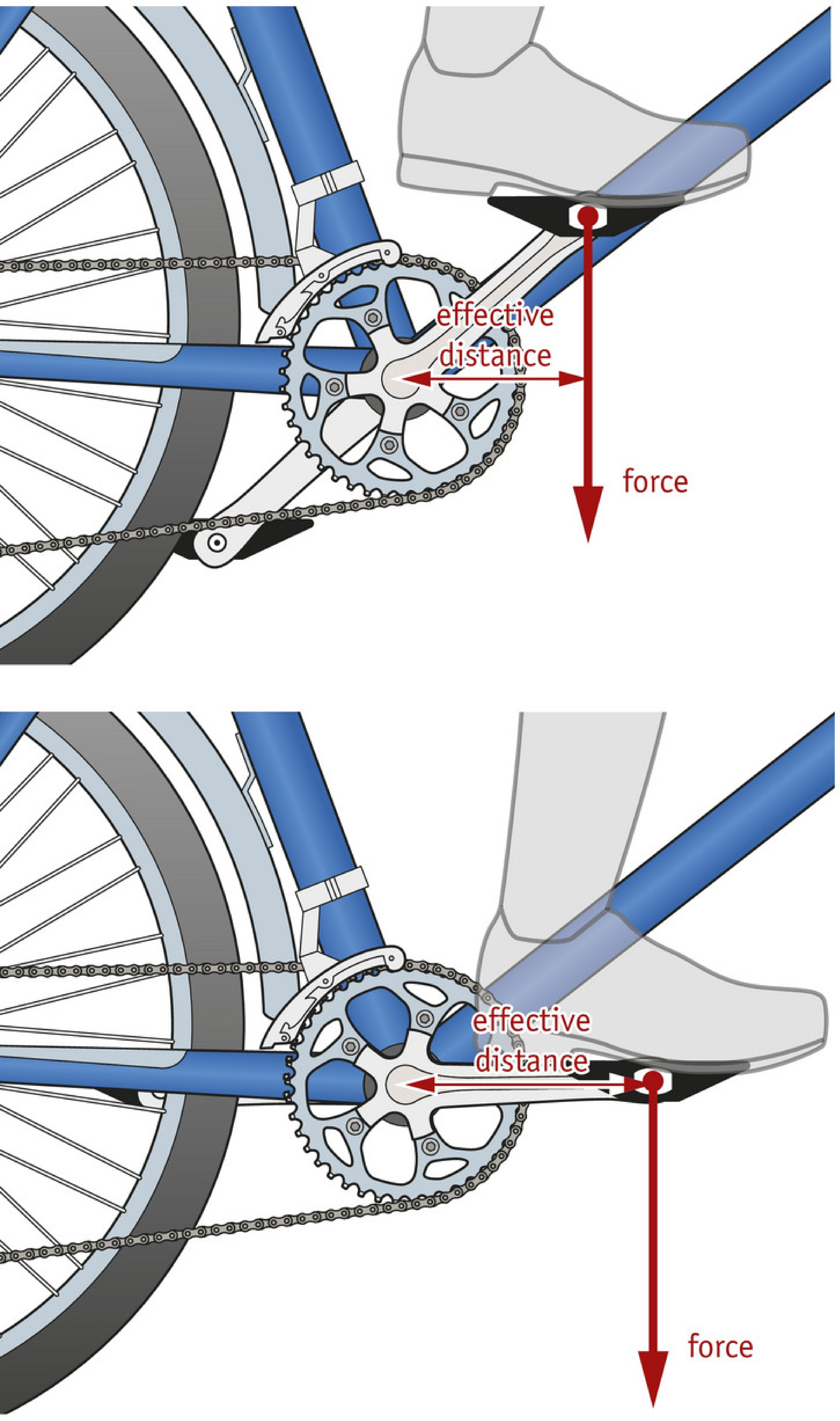
Figure 32 shows a simple lever.

- In situation a, the lever is not in equilibrium. If you let go of it, it will rotate to the left (anticlockwise).
- In situation b, the lever is in equilibrium.
- In situation c, the lever is not in equilibrium. If you now let go of it, it will rotate to the right (clockwise).



▶ figure 32
three situations for a lever

The forces on the lever are always the same size: the number of weights does not change. That does not mean that it is balanced, though. *Where* the forces are applied also matters. Two factors are therefore important for equilibrium: the size of the force and the distance between the forces and the fulcrum.



▲ figure 33
This is how you can determine the effective distance for the force on the pedals.

These two factors can be combined into a single concept, the **moment** of the force. The moment of a force is the magnitude of the force × the distance of the line of action of the force from the fulcrum. Or expressed as a formula:

$$M = F \cdot r$$

If you state the force F in N and the length of the arm r in m, you get the moment M in newton-metres (Nm).

The length of the arm r is the distance between the **line of action** of the force and the fulcrum of the lever. Figure 33 shows you how the distance from the fulcrum is measured: perpendicular to the line that the force is acting along. This is often less than the distance between the fulcrum and the point of application of the force (as measured along the line of the lever).

The law of levers

There are two forces acting on the lever in figure 34, one on the left and one on the right. Whether the lever is balanced depends on the moments of these forces. The system is in equilibrium if the moment of force F_1 (anticlockwise) equals the moment of force F_2 (clockwise). In general, a lever is balanced if the sum of the clockwise moments is equal to the sum of the anticlockwise moments. Expressed as a formula:

$$M_1 + M_2 + \ldots \text{ (anticlockwise)} = M_1 + M_2 + \ldots \text{ (clockwise)}$$

This rule is known as the **law of levers**.

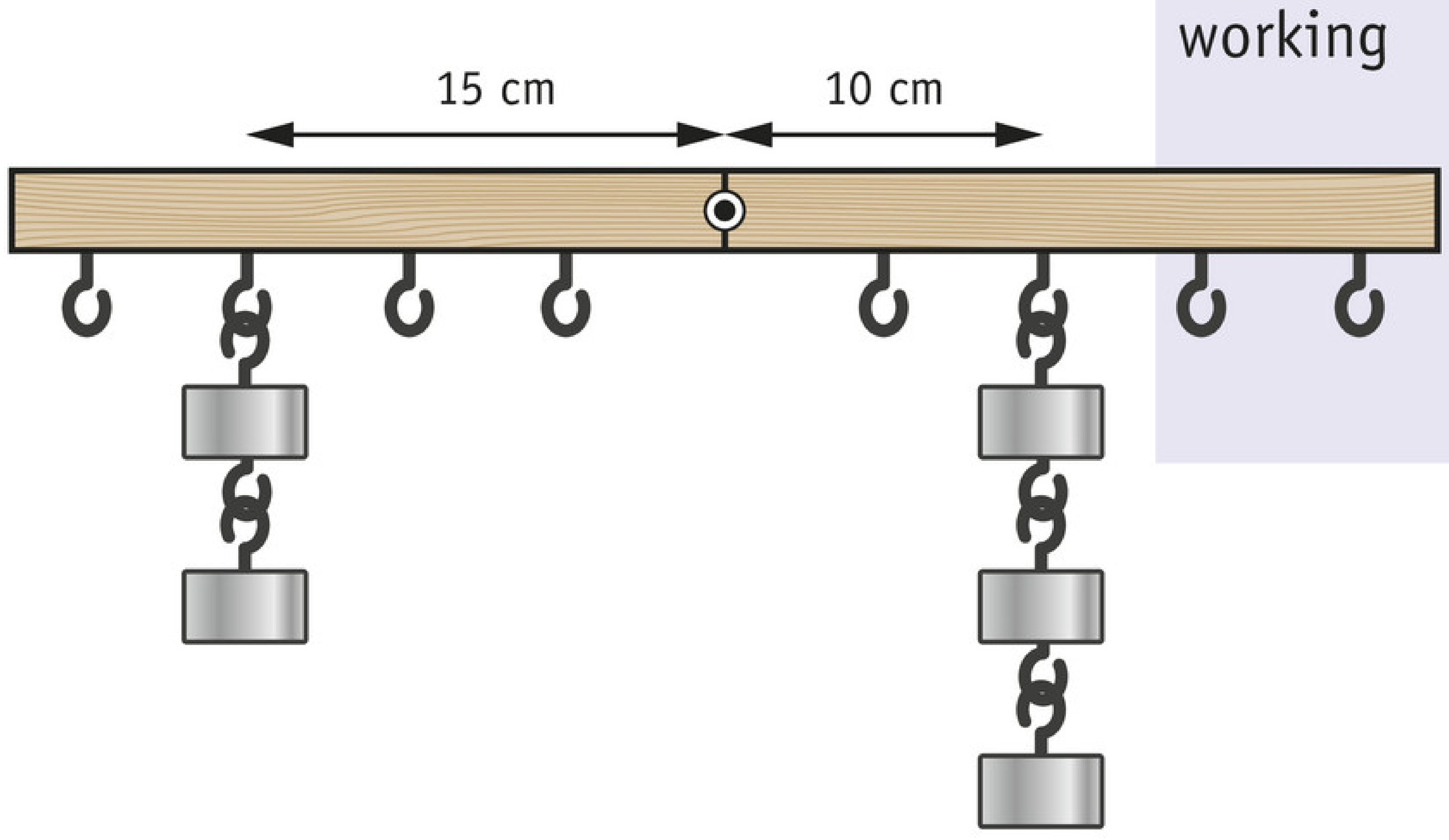
Worked example 4
Do a calculation to see if the lever in figure 34 is balanced or not. All five of the weights are equally heavy: 0.25 N.

data $\quad F_1 = 2 \times 0.25 = 0.50$ N $\quad F_2 = 3 \times 0.25 = 0.75$ N
$\quad\quad r_1 = 15$ cm $= 0.15$ m $\quad r_2 = 10$ cm $= 0.10$ m

required $\quad$ Is M_1 the same as M_2?

working $\quad M_1 = F_1 \cdot r_1 \quad M_2 = F_2 \cdot r_2$
$\quad\quad = 0.50 \times 0.15 \quad = 0.75 \times 0.10$
$\quad\quad = 0.075$ Nm $\quad = 0.075$ Nm

$M_1 = M_2 = 0.075$ Nm. The lever is therefore balanced.

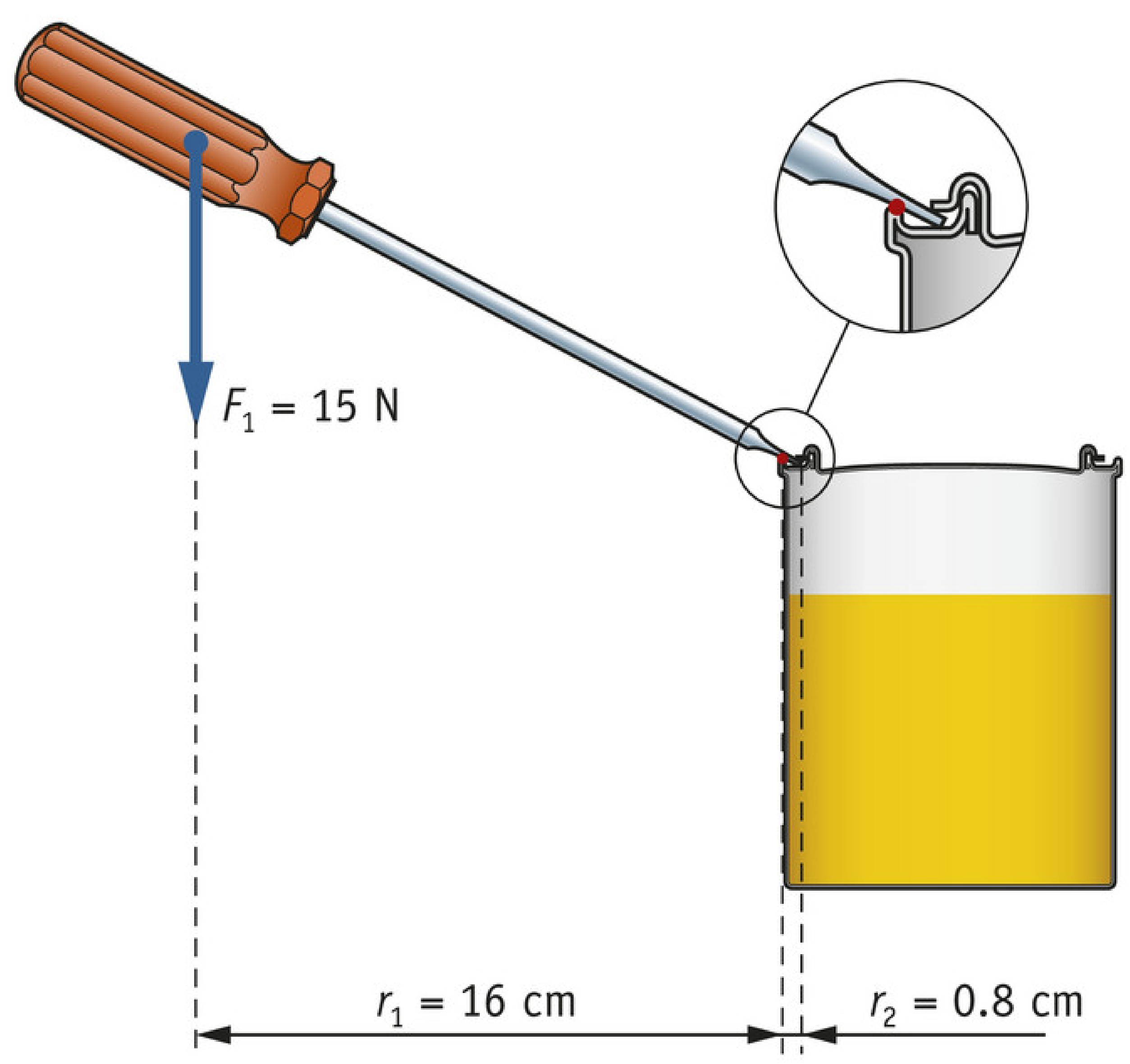


◀ figure 34
Is the lever in equilibrium?

Single and double levers

You can apply the law of levers to tools such as the screwdriver in figure 35. Your hand attempts to rotate the screwdriver anticlockwise with a force F_1. The lid resists that movement with a force F_2. The two forces F_1 and F_2 are at their maximum just before the lid starts to move. At that point there is still an equilibrium and the two moments are identical. That means that:

$$F_1 \cdot r_1 = F_2 \cdot r_2$$



▲ **figure 35**
Using a lever to open a tin of paint.

From the formula, it follows that F_2 (applied at a distance of 0.8 cm) is 20× greater than F_1 (applied at a distance of 16 cm). The force applied to the lid is therefore 300 N, 20× greater than your muscular strength of 15 N.

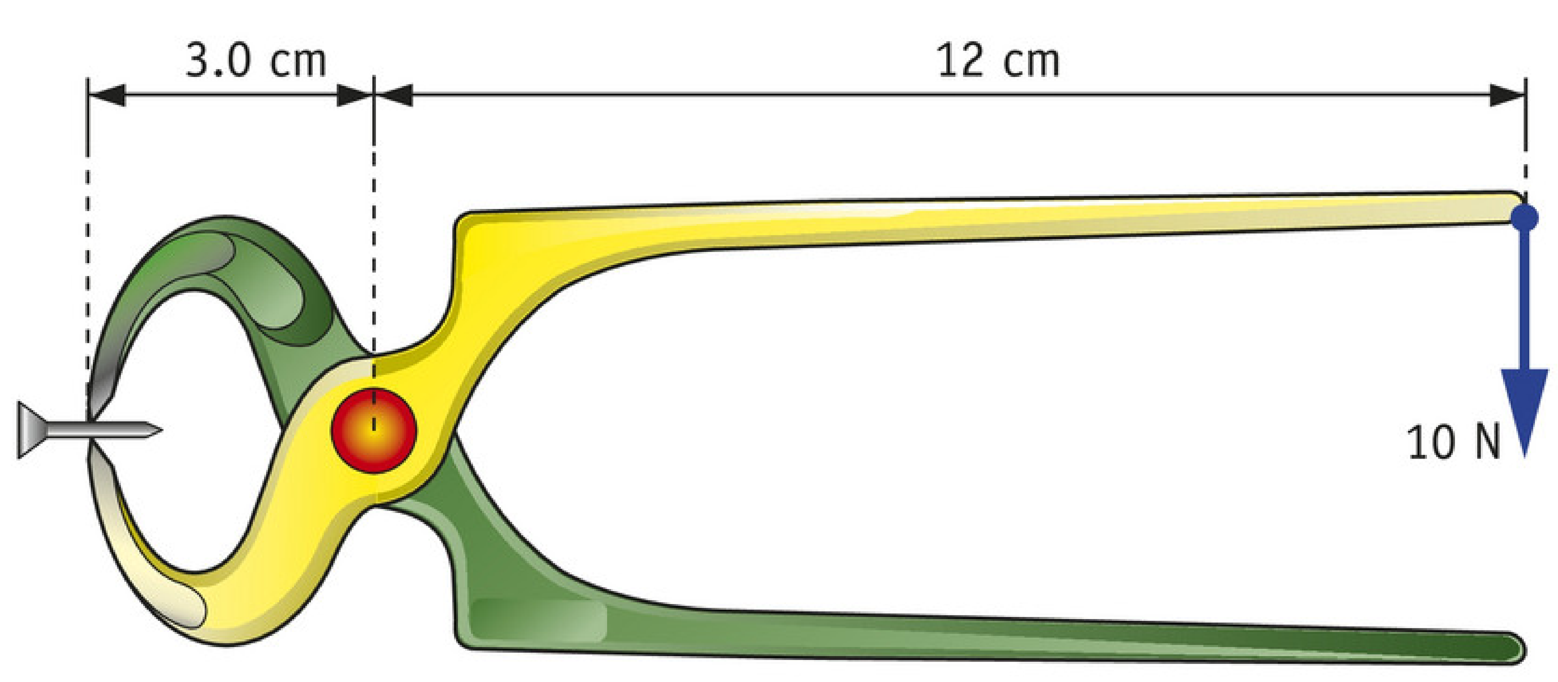
This is how a lot of tools work: a small force applied a long way from the fulcrum is balanced by a large force applied a short distance from the fulcrum. You can see this both in simple levers (such as bottle openers, spanners and tyre irons) and double levers (such as secateurs, nutcrackers and pincers).

Worked example 5
The pincers in figure 36 are squeezed with force of (two times) 10 N. Calculate the forces on the nail.

data	$F_1 = 10$ N	$F_2 = \dots$ N
	$r_1 = 12$ cm	$r_2 = 3.0$ cm
required	$F_2 = ?$	
working	Assume the system is balanced. Then:	

$F_1 \cdot r_1 = F_2 \cdot r_2$
$10 \times 12 = F_2 \times 3.0$
$F_2 = 120 \div 3.0 = 40$ N

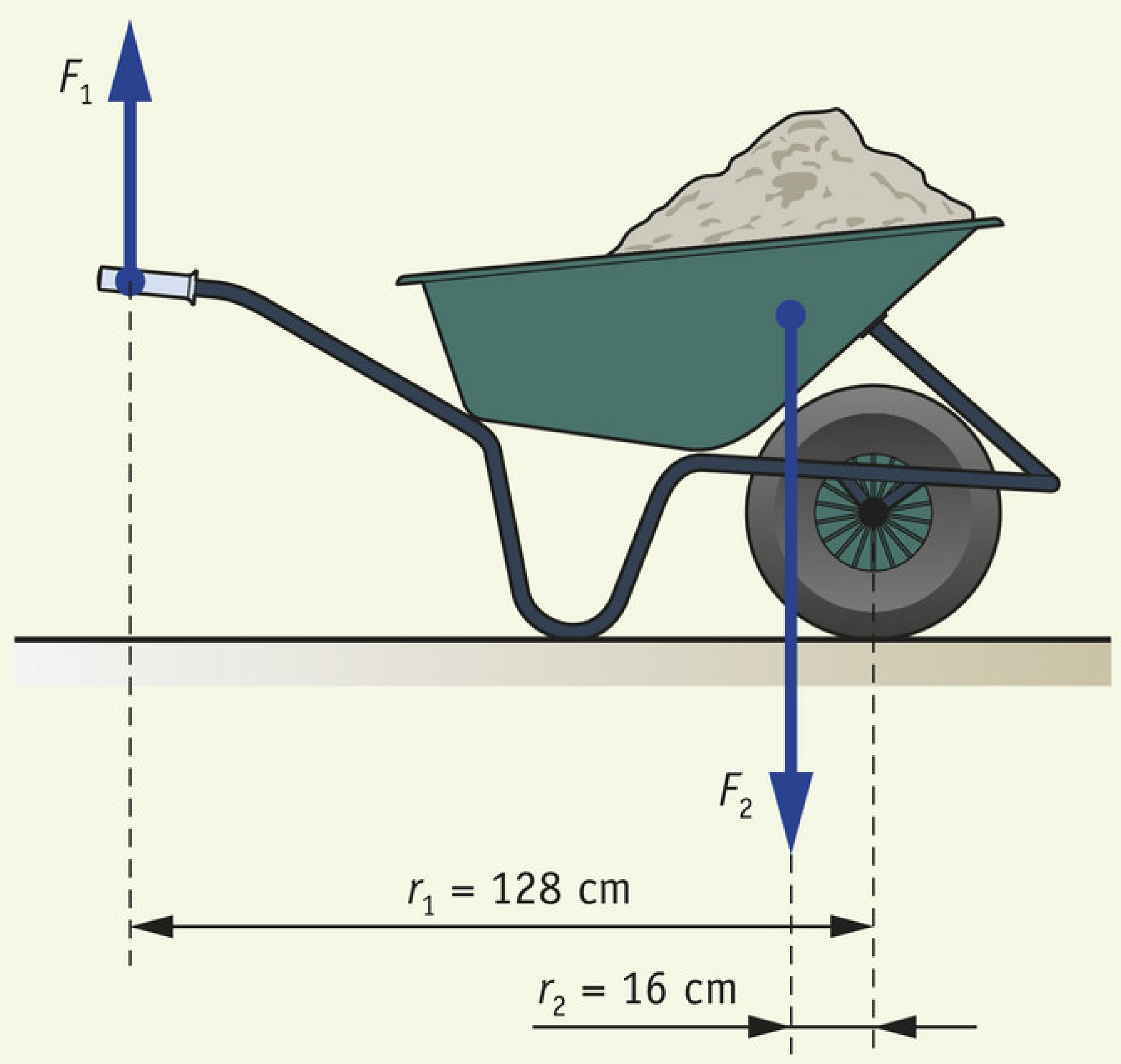
The force applied to the nail is therefore 2 × 40 = 80 N.



▶ **figure 36**
Pincers consist of two levers, which are coloured yellow and green in this example.

Plus Levers with a fulcrum at one end

For many levers, the fulcrum is located between the two forces F_1 and F_2. However, there are also levers where the fulcrum is at one of the ends. You can see that in the wheelbarrow in figure 37. The fulcrum (the axle of the wheel) is to the right of both the forces F_1 and F_2. You can apply the law of levers to these situations as well. But you do then have to be careful to measure the 'arms' of the lever correctly.



▲ **figure 37**
the forces on a wheelbarrow

Worked example 6

Khair has shovelled 100 kg of sand into the wheelbarrow. He now wants to lift the wheelbarrow up.
Calculate how much lifting force Khair requires.

data	$F_1 = \ldots$ N	$F_2 = m \cdot g = 100 \times 9.8 = 980$ N
	$r_1 = 128$ cm	$r_2 = 16$ cm
required	$F_1 = ?$	
working	Assume the system is balanced. Then:	
	$F_1 \cdot r_1 = F_2 \cdot r_2$	
	$F_1 \times 128 = 980 \times 16$	
	$F_1 = 15{,}680 \div 128 \approx 123$ N	

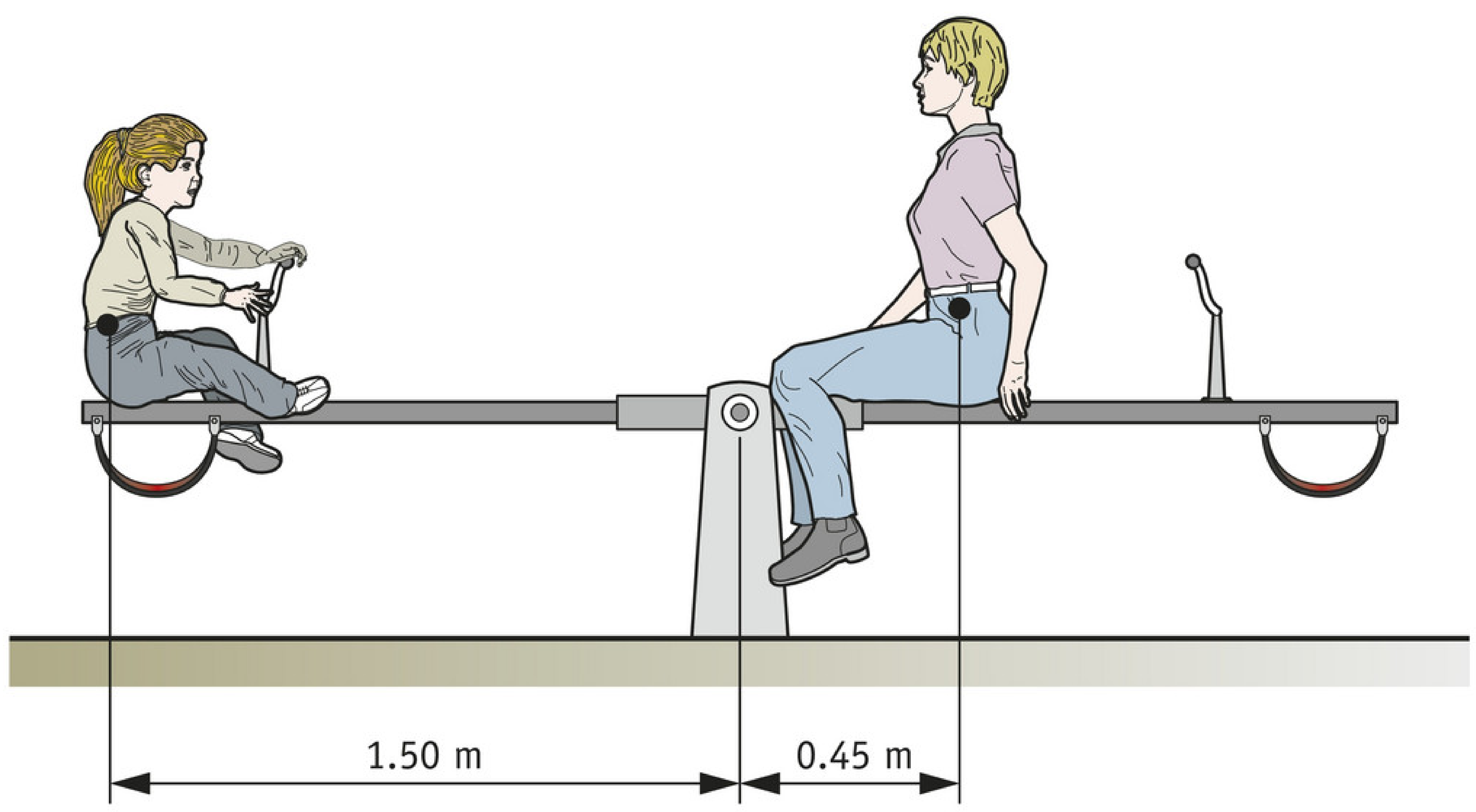
Khair therefore has to exert a force of 123 N (or in practice rather more, because we have not allowed for the wheelbarrow's own weight here).

Exercises

36 Answer the questions below.
- **a** What formula can you use to calculate the moment of a force?
- **b** How (in what direction) is the distance of the force from the fulcrum measured?
- **c** How can you determine whether a lever is balanced or not?
- **d** Why are levers used so much in daily life?

37 All kinds of tools make use of leverage.
- **a** List three tools that consist of a simple lever.
- **b** List three tools that consist of a double lever (two levers).

38 Lisette (who weighs 26 kg) and her mother Annette are sitting on a see-saw (figure 38). In the situation in the illustration, the see-saw is balanced.
- **a** Calculate the force of gravity on Lisette.
- **b** Calculate the force of gravity on Annette. Tip: use the law of levers.
- **c** Calculate Annette's mass.

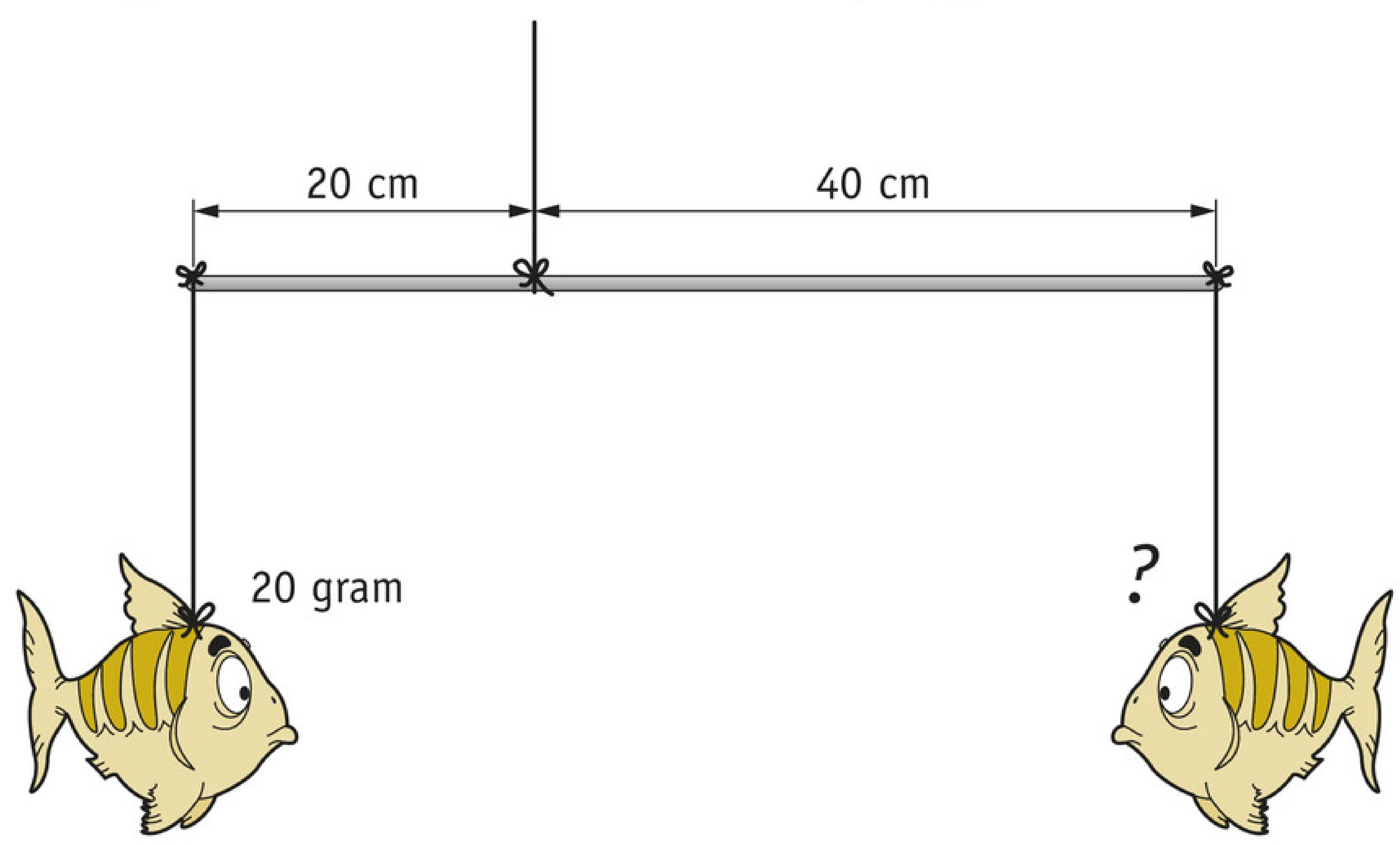


▶ **figure 38**
a balanced see-saw

39 Figure 39 shows a mobile: a structure made of lightweight sticks and figures that are balanced. To make sure that the fish shapes have the correct masses, they are weighted down on the back.

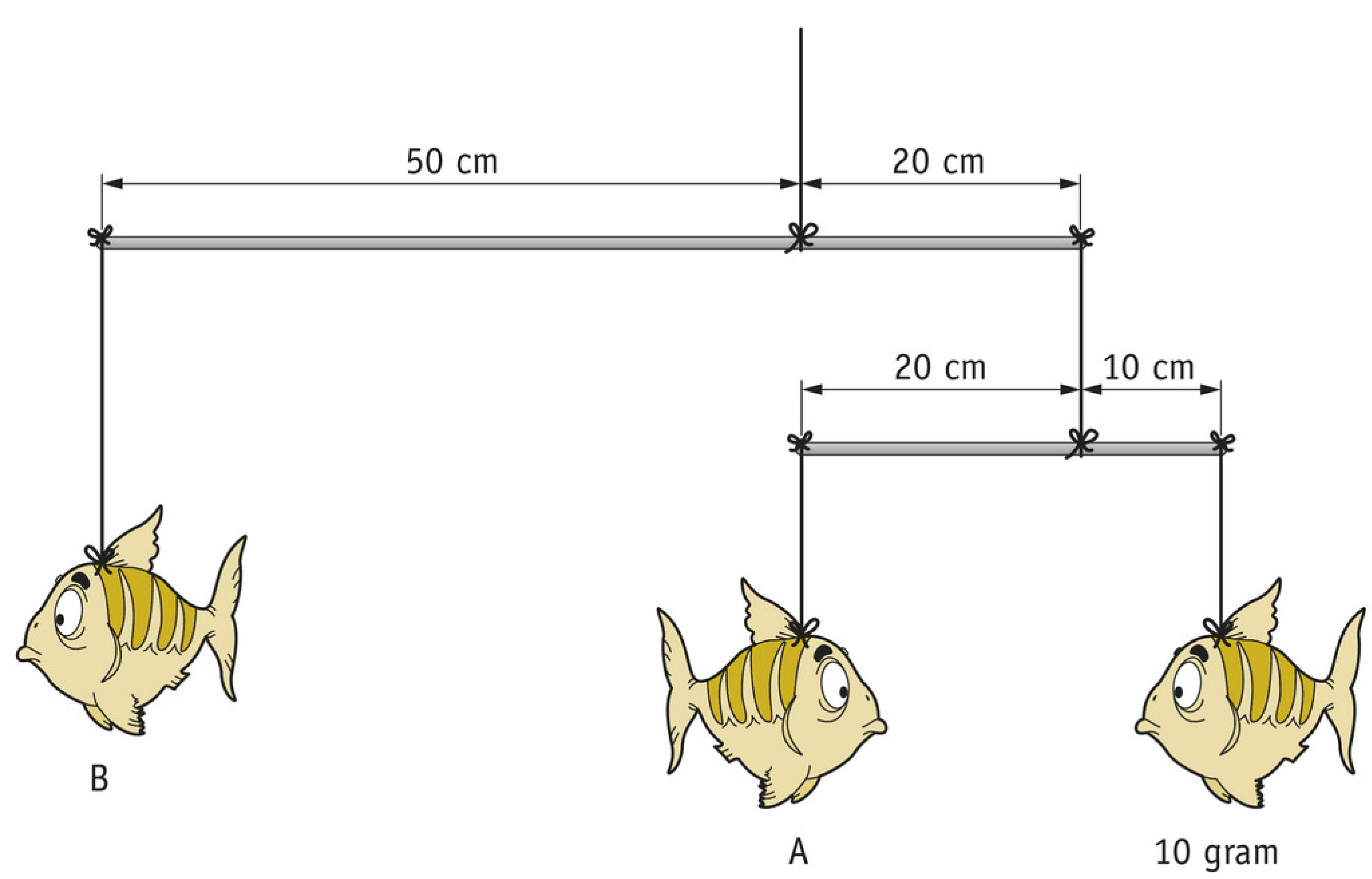
a Calculate the mass of the fish on the right. You can ignore the mass of the stick.

b Calculate the mass of the fishes on the right if you are not allowed to ignore the mass of the stick (10 g).

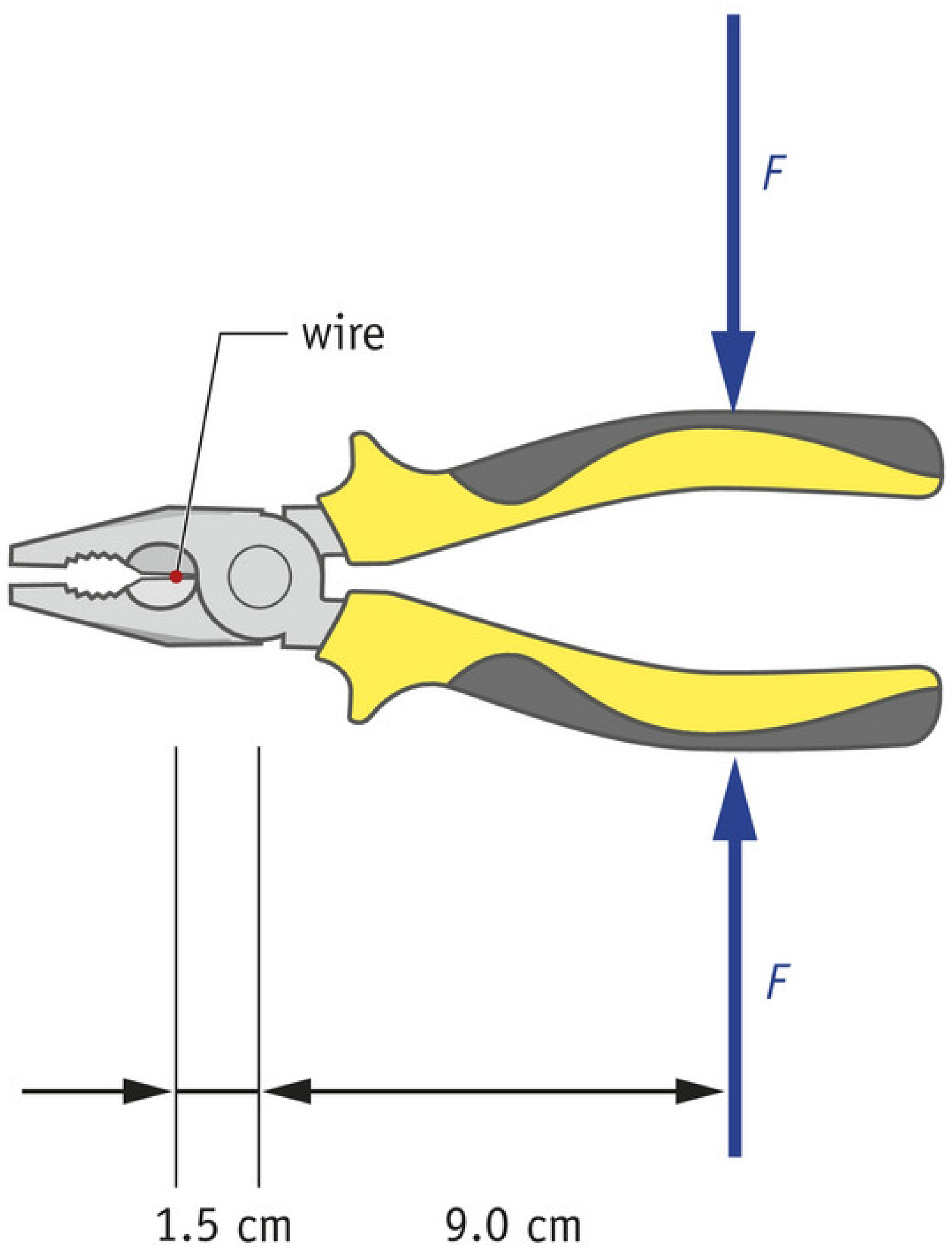


▶ **figure 39**
a mobile consisting of two fishes

40 Figure 40 shows you another, more complex mobile.
Calculate the masses of fishes A and B. You can ignore the mass of the sticks again this time.



▶ **figure 40**
a mobile of three fishes



▲ **figure 41**
cutting a wire with the wire cutters of a pair of pliers

41 You need worksheet 1-7 for this exercise.
A crate has a lid that has been nailed down all the way round. You can use a crowbar to open the crate, as shown on the worksheet.

a Place a red mark to show where the fulcrum of the crowbar is.

b Draw the direction that the muscular force has to be applied on the crowbar. The point of application has already been marked.

c Measure the distance:
- between the mechanical muscular force and the fulcrum.
- between the force on the lid and the fulcrum.

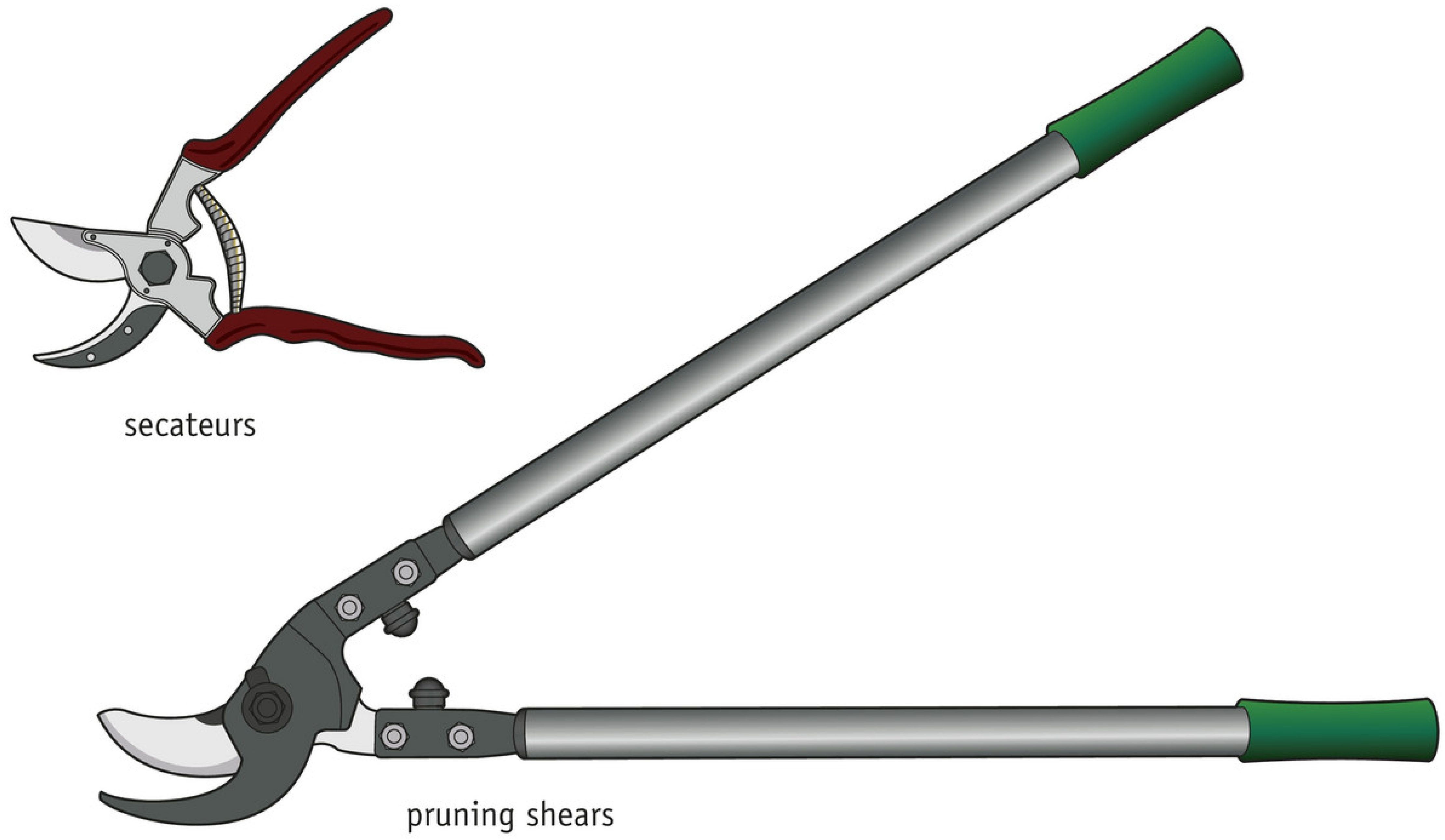
d To push the lid upwards, a force of 750 N is required.
Calculate how much (muscular) force you need to exert on the crowbar to achieve this.

42 Freddie cuts a steel wire with a pair of pliers (figure 41). This makes the pliers exert two forces of 95 N on the wire.
Calculate the muscular force *F* that Freddie used when squeezing the handle.

43 Wendy can cut through thick twigs much more easily with the pruning shears than with secateurs (figure 42).

a Explain why.

b The force exerted on a twig using the secateurs is about 4× greater than the muscular force used on the handles.
Calculate roughly how many times the pruning shears multiply the muscular strength.



▶ **figure 42**
Garden tools use levers a lot too.

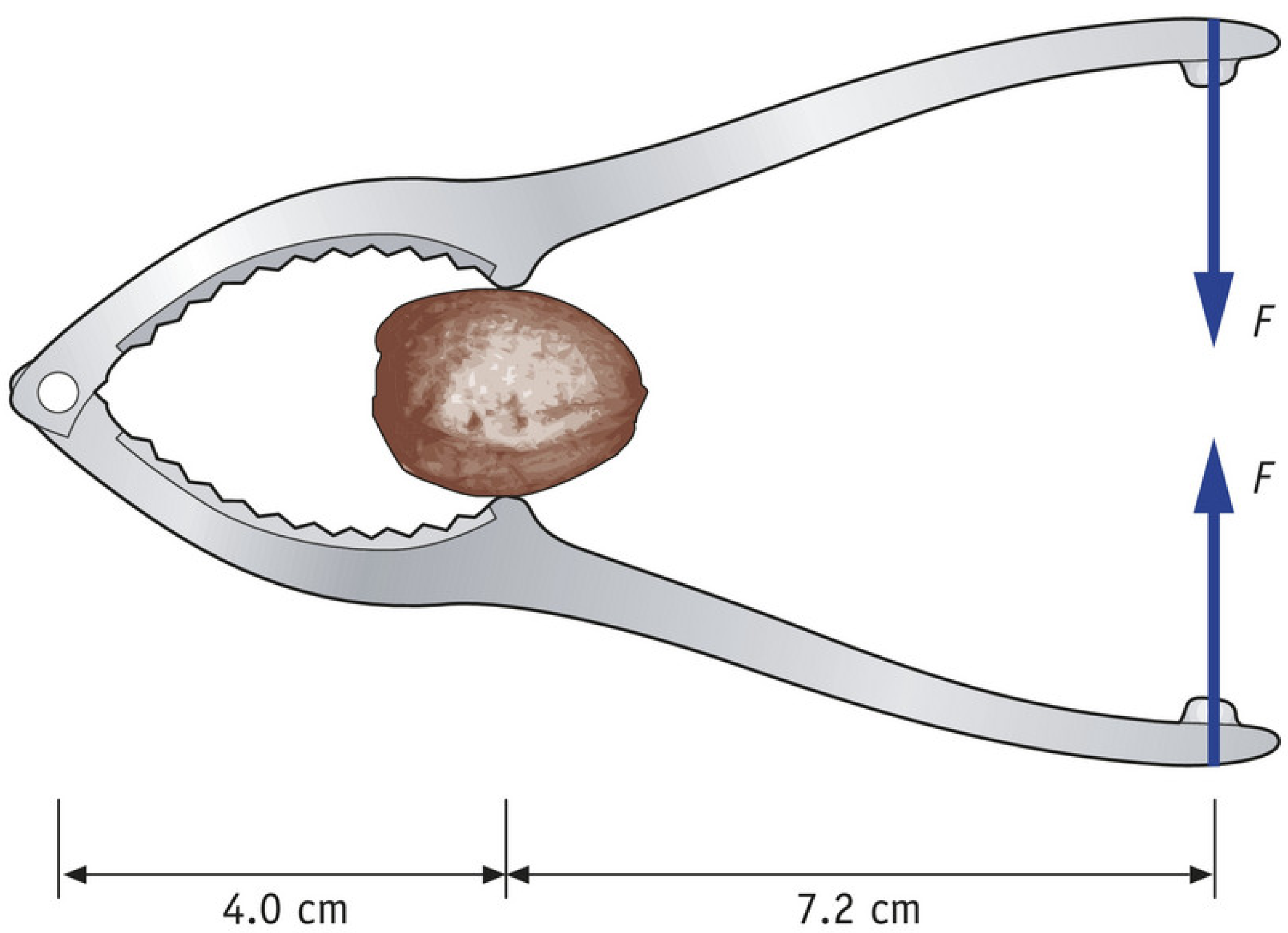
***44** Figure 43 shows you the tuning pegs of an electric guitar and a bass guitar.

a Make a sketch showing how the tuning peg acts as a lever.
b In your drawing, show the effective distance at which the muscular force is acting at.
c Explain why the bass guitar has extra large tuning pegs.

▼ **figure 43**
the tuning pegs of an electric guitar (a) and a bass guitar (b)

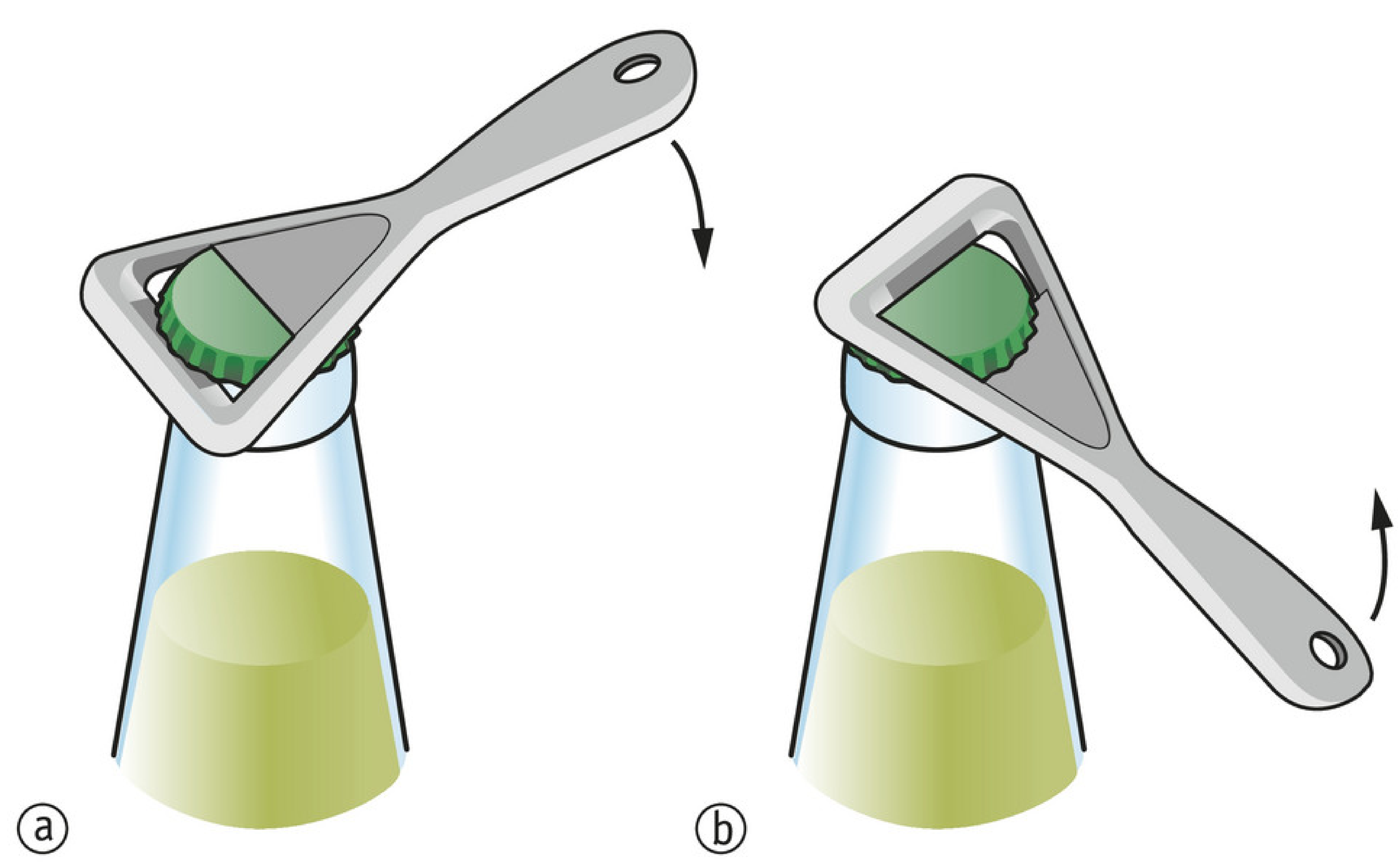
Plus Levers with a fulcrum at one end

45 Harris is using nutcrackers to open a walnut (figure 44). He exerts a force of 15 N on both handles. Calculate the force applied to the walnut.



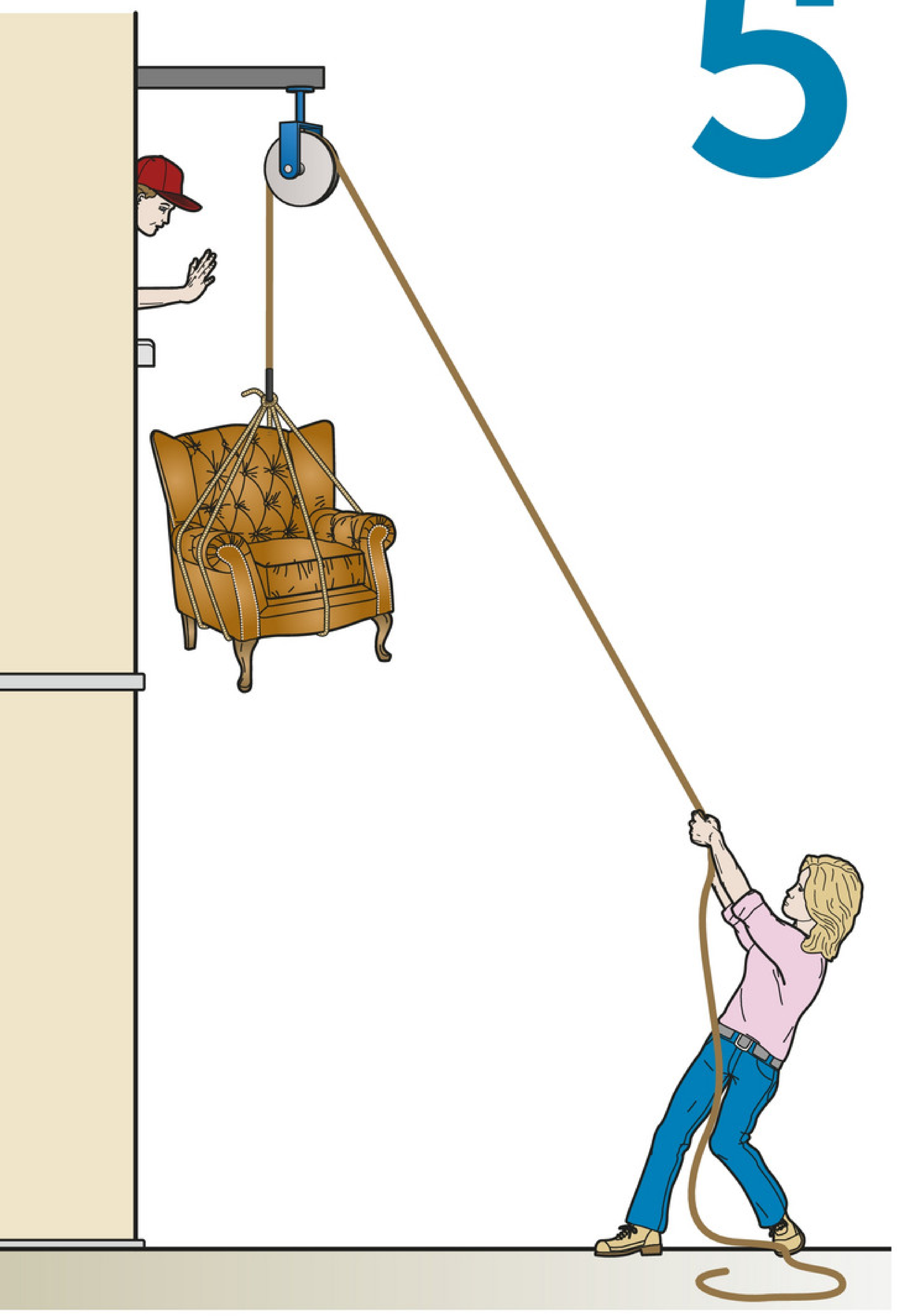
▶ **figure 44**
cracking a nut

***46** There are two different ways that you can use a bottle opener to open a bottle (figure 45).
Calculate which way requires less muscular strength. Tip: make a sketch showing the fulcrums and the effective distances of the forces.



▶ **figure 45**
Which is the easiest way to open the bottle?

5 Applying forces



▲ figure 46
hoisting using a fixed pulley

You can use a rope to transmit a force. To do that, you have to tie the rope to an object. When you then pull on the loose end, the rope is tightened. This transfers your muscular force to the object at the other end. This lets you pull the object forward or raise it up.

A fixed pulley

Figure 46 shows you how a chair weighing 20 kg is being lifted. The rope goes over a **fixed pulley**. That is a pulley that is fixed at one place and cannot move up and down. To lift the chair, you must pull the rope with a force of 196 N. Right at the beginning, the lifting force is slightly more than 196 N, otherwise the chair will not start to move, but you may ignore that little bit of extra force for now.

As you lift, you are doing **work**. The amount of work that you do depends on two things: the force with which you are pulling on the rope and the distance through which you move the object. You can express the amount of work using the formula:

$$W = F \cdot s$$

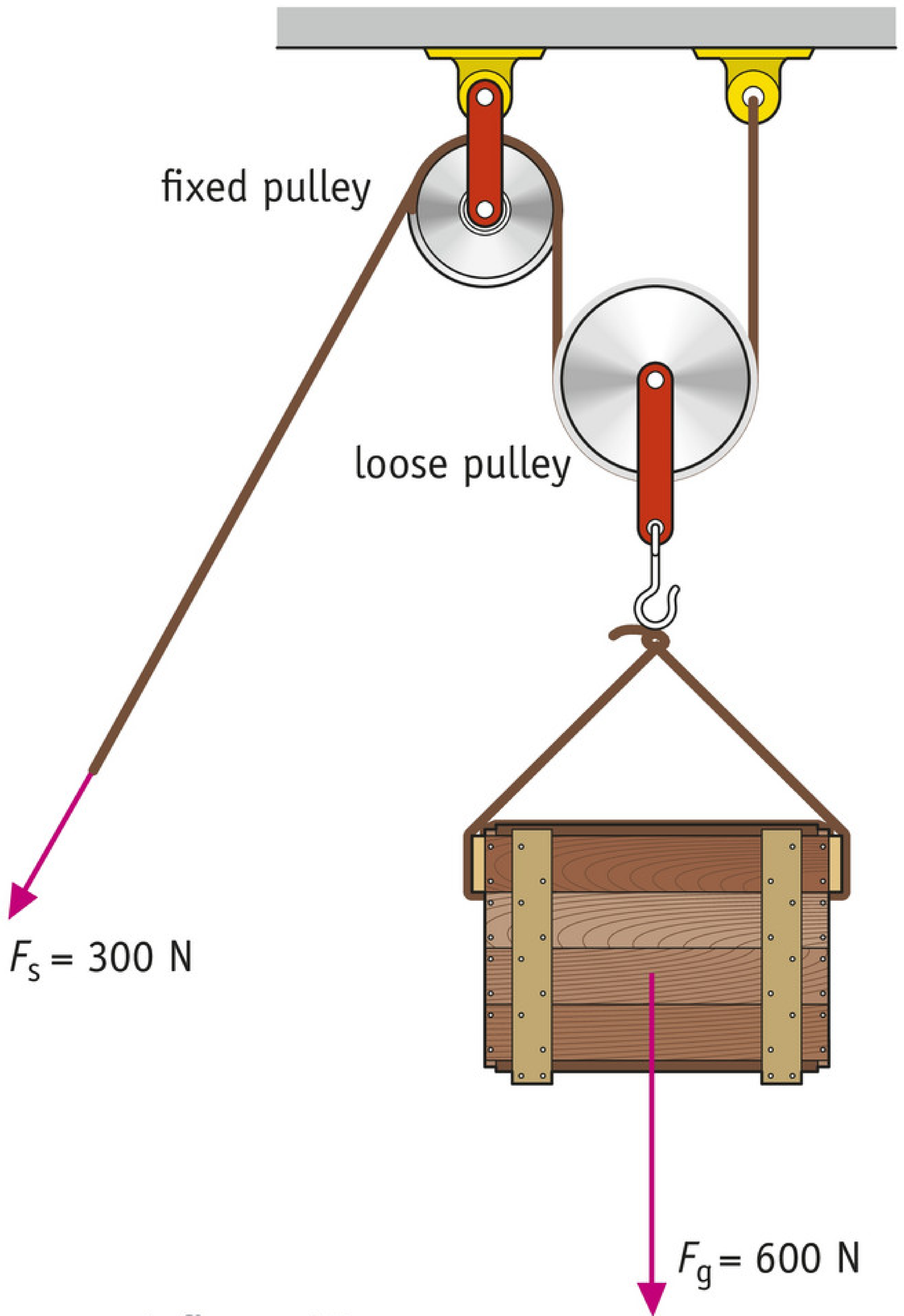
If you give the force F in N and the distance s in m, you will calculate the amount of work done W in newton-metres (Nm).

A fixed pulley does not mean that you have to pull less hard on the rope. It only alters the direction of the force. Even so, this kind of pulley is a useful tool. It is easier to pull a rope downwards than to lift an object upwards: you can easily put your whole weight on the rope until you are almost hanging from it.

Hoisting with a block and tackle Experiment 4

Many objects are so heavy that you cannot lift them using a fixed pulley. For example, think of a piano that has to be lifted up to an attic room. Even if you apply your whole weight by hanging from the rope, the piano will not budge. For situations like these, you need a **block and tackle**.

Figure 47 shows a block and tackle with one fixed pulley and one **loose pulley**. The loose pulley can go up and down, along with the object that is being moved. In this block and tackle, the object is hanging by two pieces of rope, one end is fixed to the ceiling, and you have the other end in your hand.



▲ figure 47
hoisting with a block and tackle

▲ figure 48
These blocks and tackles can be used for lifting very heavy weights.

The crate in figure 47 has a mass of 60 kg. The load is therefore 600 N. However, you only have to pull on the rope with a force of 300 N. This is because the crate is hanging by two pieces of rope. Each piece of rope exerts a force of 300 N: the section on the left because you are pulling on it, and the section on the right because it is attached to the ceiling. Together, the two pieces of rope provide 600 N, which is enough to hoist the crate.

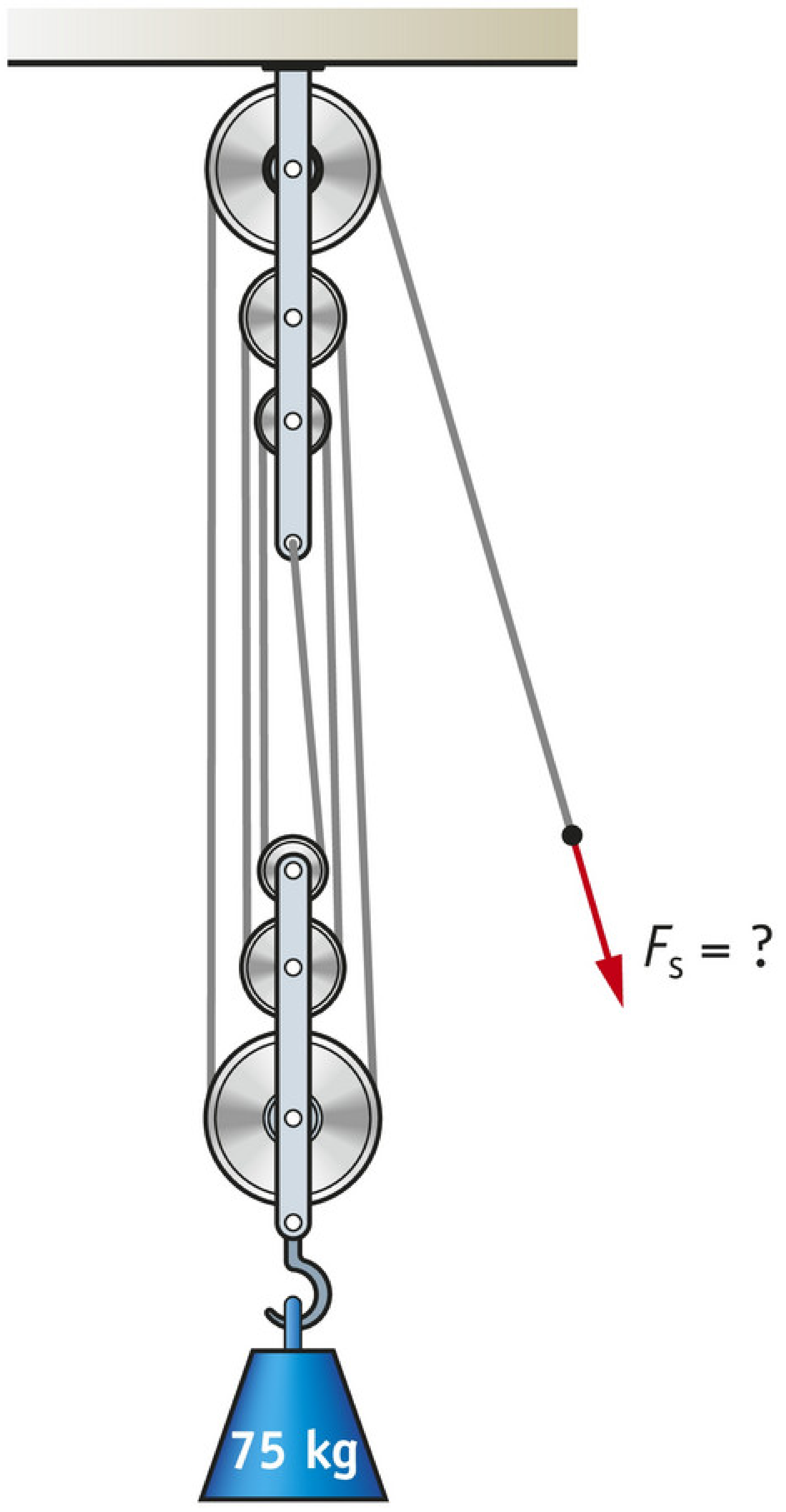
Gains and losses

The block and tackle shown in figure 47 makes the **hoisting force** on the object 2× larger (compared to the muscular mechanical force on the rope): you only have to pull the rope with a force of 300 N to lift an object weighing 600 N. The job of lifting is now much easier. That is what you gain from the block and tackle.

There is however a disadvantage as well. Both the two pieces of rope that the crate is hanging from have to be made shorter. This means that the crate only goes up by 1.0 m when you pull the rope down by 2.0 m. The **hoisting distance** therefore becomes 2× smaller. That is what you lose from the block and tackle.

Many blocks and tackles have more than two pulleys (figure 48). The more pulleys there are, the greater the lifting force and the smaller the hoisting distance. The rule for any block and tackle is that:

If the object is hanging from N pieces of rope, the hoisting force is N× greater and the hoisting distance is N× smaller.



▲ figure 49
Adrian's block and tackle

Worked example 7
Adrian is using the block and tackle in figure 49 to lift an object of 75 kg through a distance of 8.0 m.
Calculate how hard Adrian has to pull on the rope and how many metres of rope he has to haul in.

data	The object is hanging by six pieces of rope, so $N = 6$. m = 75 kg h = 8.0 m
required	the muscular force needed and the number of metres of rope that has to be hauled in
working	$F_z = m \cdot g$ $= 75 \times 9.8$ $= 735$ N

The muscular force required is $F_g \div N = 735 \div 6 \approx 123$ N.
The number of metres of rope that Adrian needs to haul in is $h \cdot N = 8.0 \times 6 = 48$ m.

The amount of work remains the same

It makes no difference to the amount of work whether you simply lift something or use a block and tackle. If you multiply the force (at the tackle where it is $N\times$ larger) by the distance (at the tackle where it is $N\times$ smaller), you get the same answer in both cases.

An example. If Adrian in worked example 7 had used a fixed pulley, you would have calculated the amount of work like this:

$W = F \cdot s = 735 \times 8.0 = 5880$ Nm

In reality, he used the block and tackle with $N = 6$. The calculation then becomes:

$W = F \cdot s = 122.5 \times 48 = 5880$ Nm

As you can see, the amount of work is the same in both cases: 5880 Nm. The block and tackle only makes it easier to perform that work.

Plus Hoisting equipment

Many objects are too heavy for you simply to lift them. If you do want to lift them, you need a tool such as a jack, a block and tackle or a slope. The rules for this type of **hoisting equipment** is that it does reduce the force required, but not the amount of work: that stays the same. In other words:

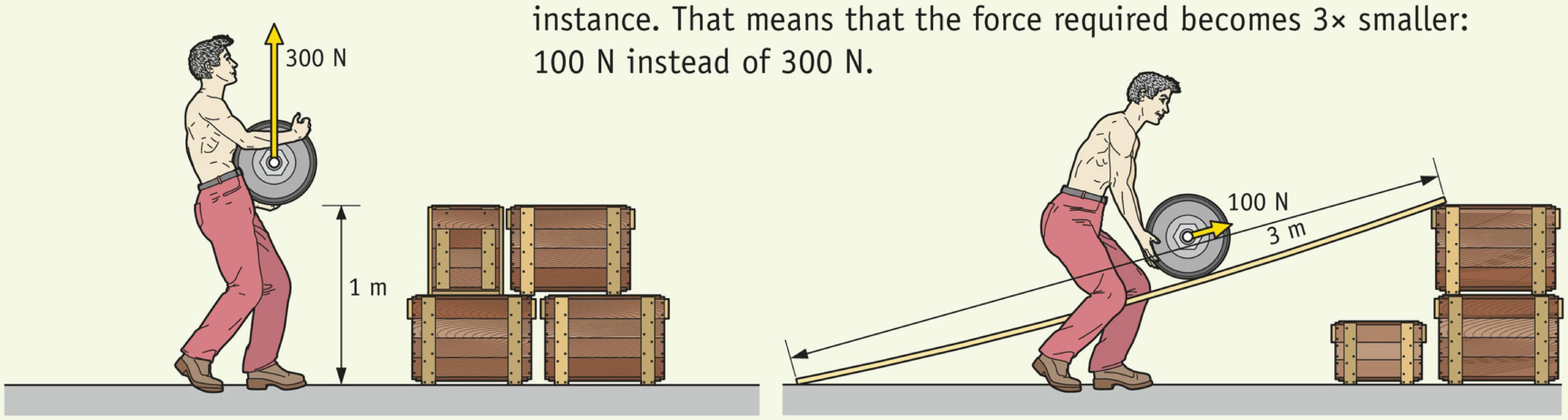
> If hoisting equipment makes the force required $N\times$ smaller, the distance to be covered will become $N\times$ greater.

and vice versa:

> If hoisting equipment makes the distance to be covered $N\times$ greater, the force required will become $N\times$ smaller.

The sloping plane in figure 50 makes the distance 3× greater, for instance. That means that the force required becomes 3× smaller: 100 N instead of 300 N.

▼ **figure 50**
What would you do: simply lift, or use the slope?



Exercises

47 Answer the questions below.
- **a** What lifting force is required to hoist an object of 20 kg?
- **b** What formula can you use to calculate the work done to lift an object?
- **c** What is the difference between a fixed pulley and a loose pulley? Illustrate this with a drawing.
- **d** How can you determine how many times greater a block and tackle makes the hoisting force?

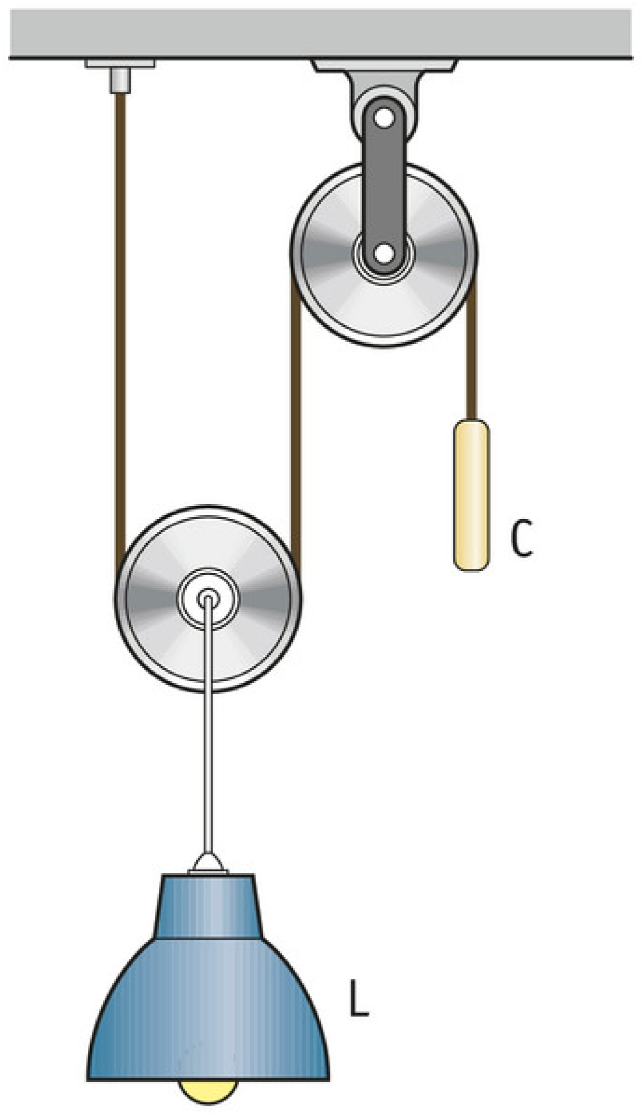
48 If you use a block and tackle to lift something, you gain in some respects and lose in others.
- **a** What do you gain by using a block and tackle?
- **b** What do you lose to make this possible?
- **c** What remains constant if you use a block and tackle?

49 Robert (86 kg) is moving to a flat on the third floor of a former warehouse. He is using a fixed pulley to hoist his furniture.
- **a** What is the maximum pull that Robert is able to exert on the rope? Explain how you got your answer.
- **b** During hoisting, Robert takes a couple of steps backwards. The rope he is pulling on is then at an angle.
  Does this also change the force that Robert has to exert on the rope?

50 Calculate the work done in the following situations.
- **a** Joey picks up a box of matches from the ground and puts it on the table. The mass of the box of matches is 10 g and the table is 78 cm high.
- **b** Flora puts her bike on the roof rack of the car. The mass of the bicycle is 26 kg and the roof rack is 1.45 m above the ground.
- **c** The crane at a scrap metal yard lifts an old car up by 3.5 m. The mass of the scrap car is 940 kg.
- **d** A tower crane lifts a concrete floor element to a height of 70 m. The mass of the floor element is 1350 kg.

51 A removal man hoists a chair using a fixed pulley. The mass of the chair is 12 kg and it is lifted 7.5 m.
- **a** Calculate the muscular force required.
- **b** How many metres of rope does the removal man have to haul in?
- **c** Calculate the amount of work done by the removal man.

52 Continuation of exercise 51.
Suppose that the removal man had used to block and tackle with one fixed pulley and one loose one to hoist the chair.
- **a** How much muscular force would have been needed then?
- **b** How many metres of rope would the removal man have had to haul in?
- **c** Calculate the amount of work that the removal man would have done.
- **d** Compare the answers for questions 52c and 53c.
  What do you notice?



▲ **figure 51**
a light on a pulley

53 Marie and Gary are hanging up an adjustable light on pulleys (figure 51). The light has a mass of 1.5 kg. You may ignore the mass of the loose pulley and the friction in the pulleys.

- **a** Cylinder C is heavy enough to hold the light in place.
  Calculate the mass of the cylinder.
- **b** Marie pushes the light 20 cm upwards.
  Why does she have to exert little or no force to do that?
- **c** How many centimetres will the metal cylinder come down by if Marie pushes the light upwards by 20 cm?

54 Fran (22 kg) has bet her father (79 kg) that she can lift him up all on her own. But Fran's father does not know that she has borrowed a block and tackle.

- **a** How many times greater do the block and tackle have to make Fran's lifting force?
- **b** Draw a simple block and tackle that Fran could use to win the bet. Do not draw any more pulleys than necessary.

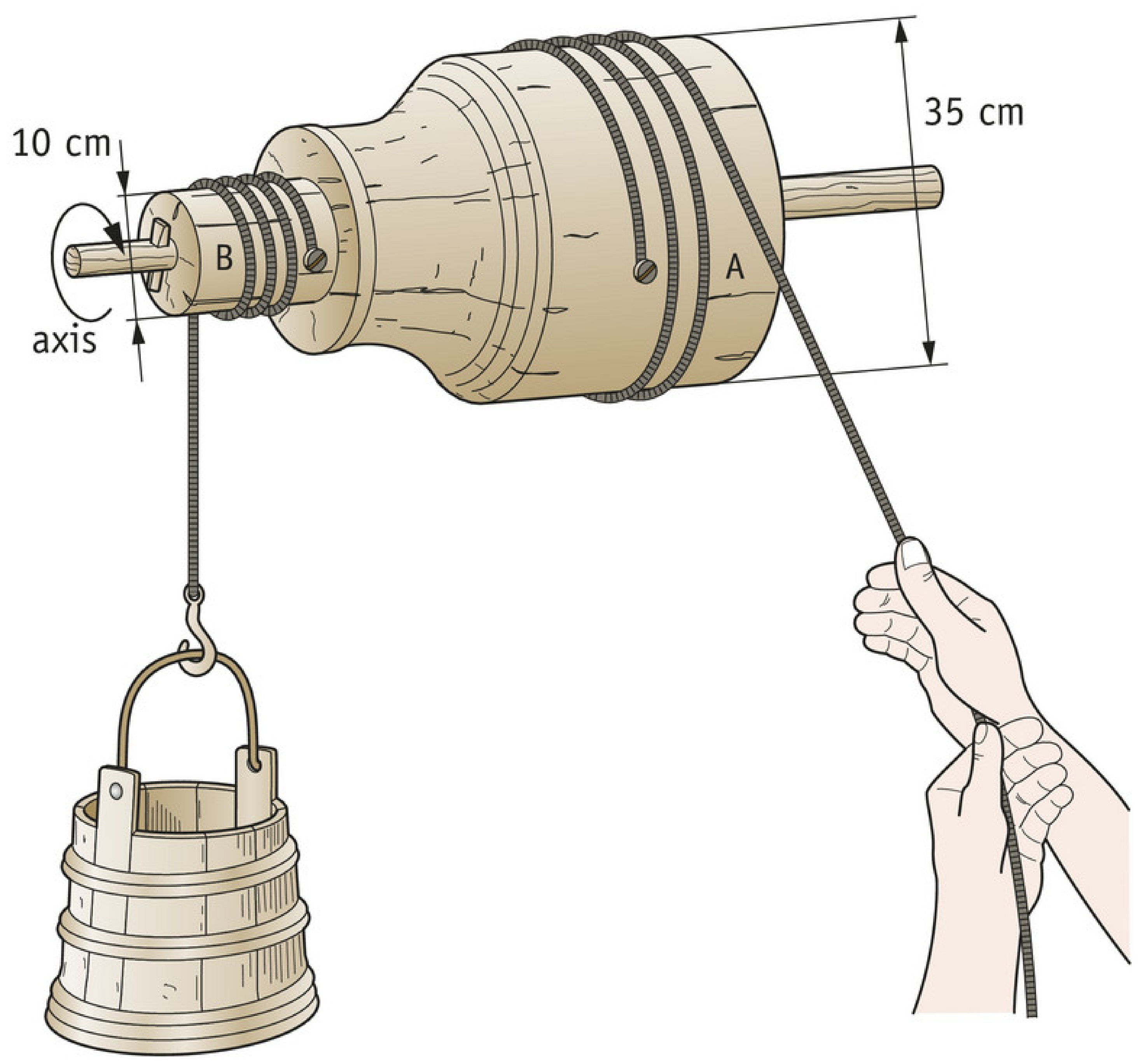
***55** Max lifts a chair of 12 kg by 7.5 m using a block and tackle that consists of one fixed pulley and one loose one. The pulleys each have a mass of 1.0 kg.

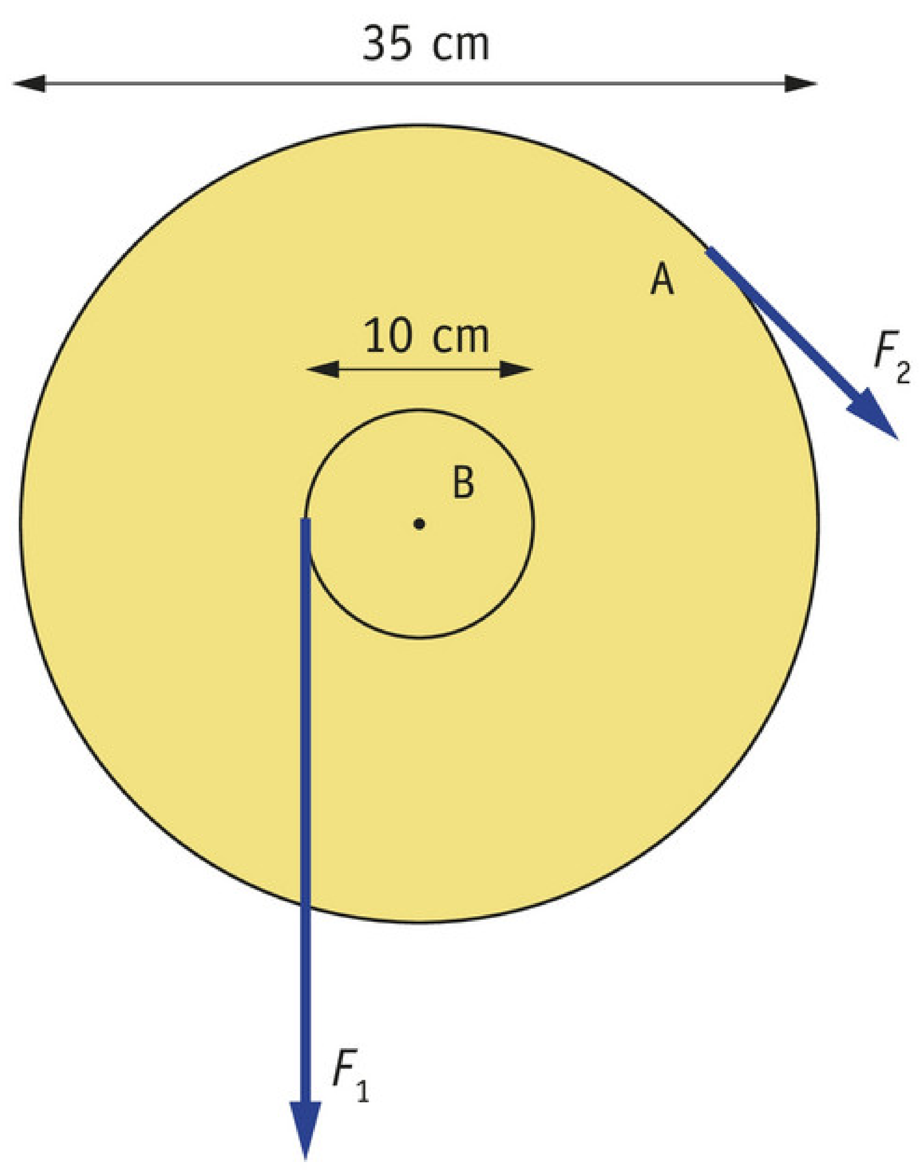
- **a** Calculate the muscular strength required.
- **b** How many metres of rope does Max have pull through?
- **c** Calculate the amount of work Max has to do.
- **d** Explain why Max would have had to do slightly more work if the block and tackle had consisted of two fixed pulleys and two loose ones.

***56** Marshall is using a windlass to hoist a bucket of water (figure 52). The mass of the bucket with water is 10 kg.

- **a** Calculate the force that Marshall must use to pull the rope. Tip: treat the windlass as a lever and use the law of levers.
- **b** At point A, 4.0 m of rope is hauled in.
  Calculate how many metres the bucket is then raised by.
- **c** If the windlass breaks, Marshall will have to lift the bucket using a loose piece of rope.
  Show that this makes a difference to the force required, but not to the amount of work done.

▼ **figure 52**
a windlass

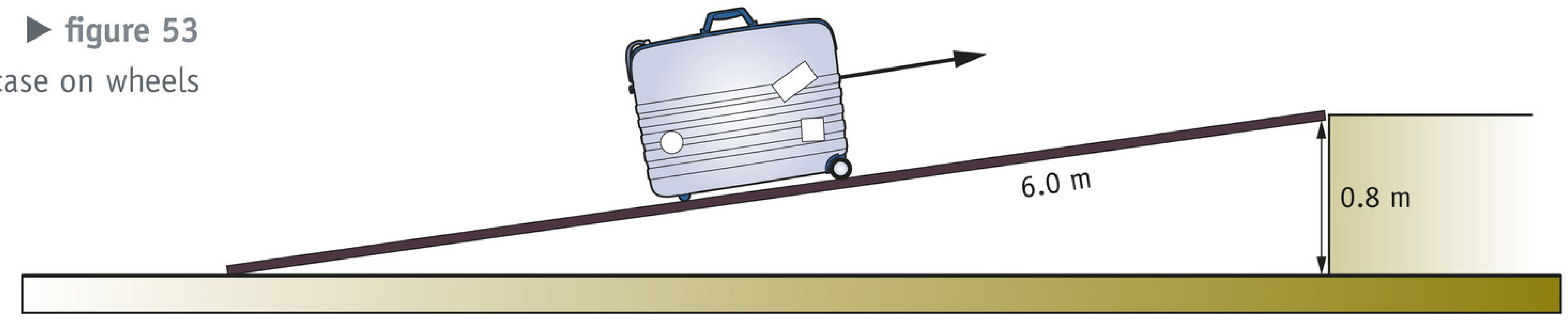




Plus Hoisting equipment

57 In the departure lounge of an airport, a passenger is pulling a wheeled suitcase up a slope (figure 53). The slope is 6.0 m long and 0.80 m high. The suitcase has a mass of 20 kg. The wheels run smoothly enough that friction may be ignored.
Calculate the work that the passenger has to do in order to lift the suitcase up along the slope.

▶ **figure 53**
a suitcase on wheels



58 A hospital bed has a kind of jack that you can use for raising it. When you push the pedal of the jack down by 20 cm, the bed goes up by 3.0 cm.
In order to lift a particular patient, the nurse has to apply a force of 165 N to the pedal.

a Calculate the mass of the bed and patient together.

b The nurse jacks up the bed by a total of 30 cm.
Calculate how much work the nurse has to do for this.

Experiments

Experiment 1 Stretching a helical spring 30 min

Introduction
A helical spring stretches if you hang weights on it. The extension is the number of centimetres by which the length of the spring increases. If a spring is 12.0 cm long with no weights on and 15.8 cm with the weights, the extension is then 3.8 cm.

Aim
You are going to investigate how a helical spring stretches. The question you are studying is:
What is the relationship between the force and the extension?

Requirements
- stands
- weight carrier
- weights
- helical spring
- ruler
- worksheet 1-8

Doing the experiment and writing it up
- Construct the setup as shown in figure 54.
- Hang the weight carrier on the spring, but with no weights.
- Note the position of the bottom of the weight carrier (the zero point).
- Then put one, two, three etc. weights successively on the weight carrier. Determine the corresponding extension of the spring each time (= new position – zero position).

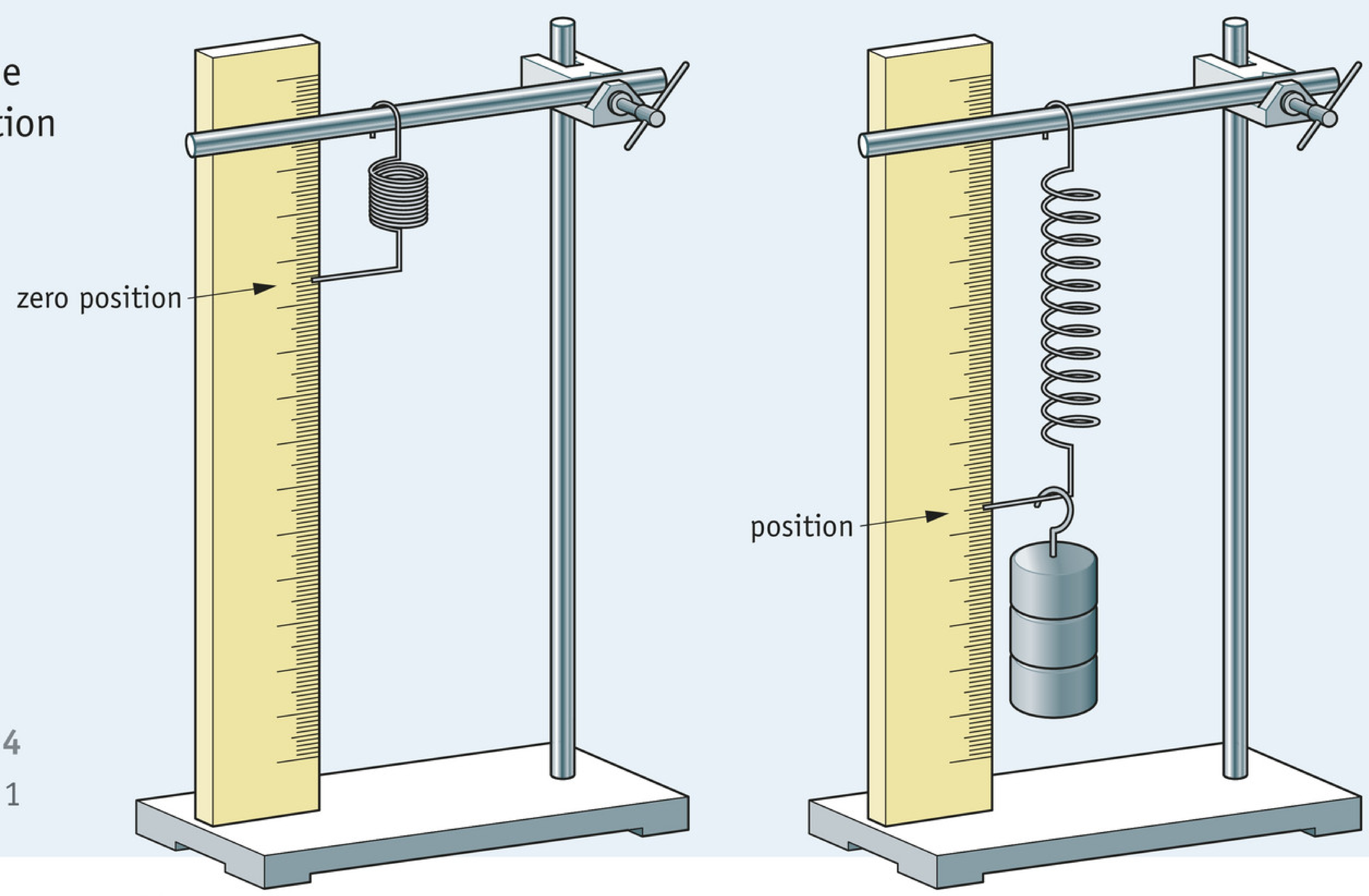
1 Take worksheet 1-8.
Write down the mass of the weights, the force on the springs and the corresponding extension in the table.

▼ **table 4** the measurement data from experiment 1

number of weights	mass of the weights (g)	force on the spring (N)	extension (cm)
0	0	0	0
1			
2			
3			
and so forth			

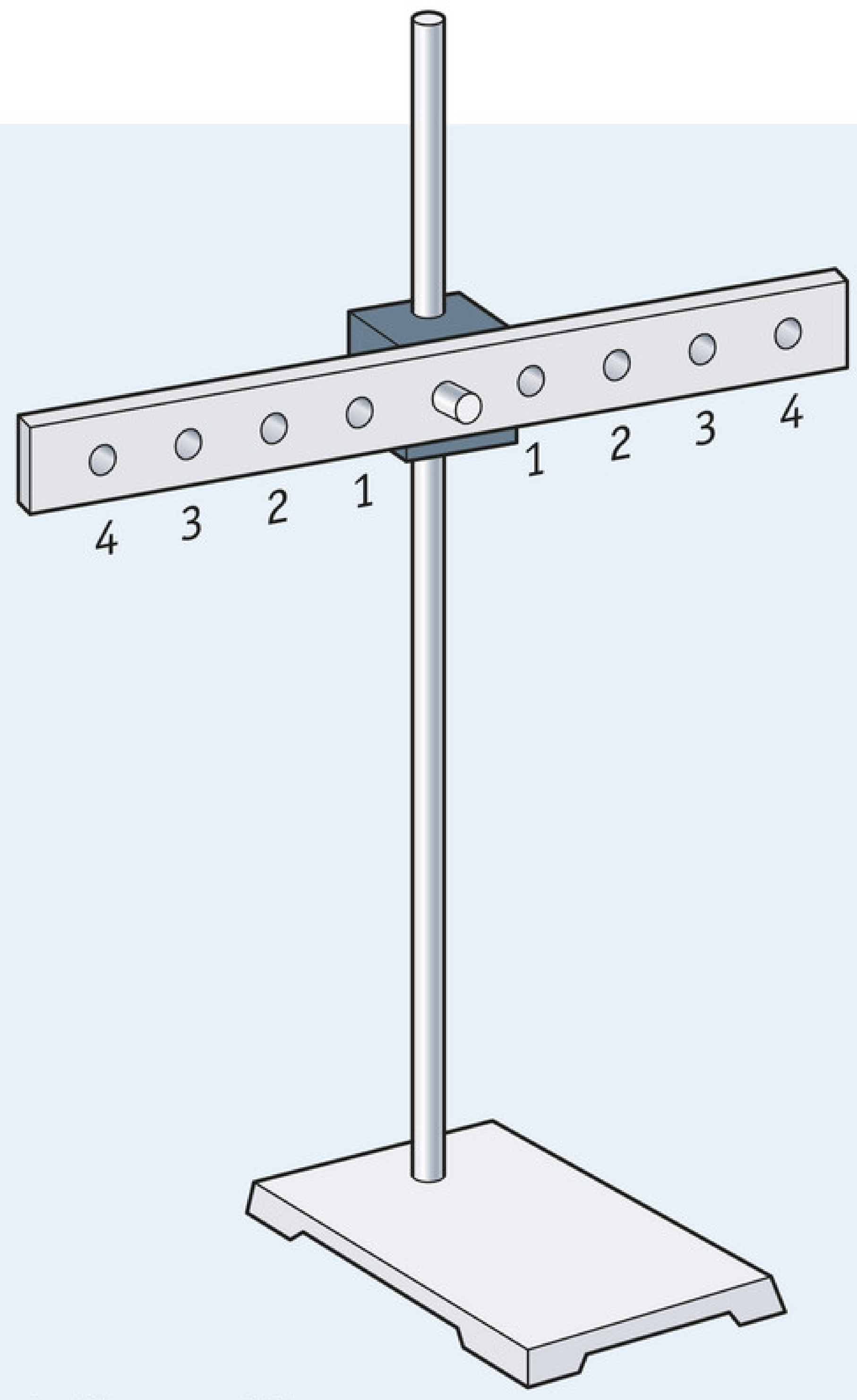
2 See 'Skills 7' at the back of the book.
Make a graph of your measurements.
3 See 'Skills 8' at the back of the book.
What kind of relationship is there between the force on a spring and the extension?
4 Determine the spring constant for your spring.
Write down how you did this.

- Your teacher will tell you whether or not you have to write up a report on this experiment.



▶ **figure 54**
the setup for experiment 1

Experiment 2 A rule for equilibrium 30 min



▲ figure 55
the setup for experiment 2

Introduction
You use levers every day. Bottle openers, spanners, bike pedals, door handles, pliers, scissors: they are all levers. Even for something as simple as opening a door, you need levers.

Aim
You are going to investigate when a lever is balanced. The question you are studying is:
What is the rule for a lever being in equilibrium?

Requirements
- stands
- a lever with holes
- 8 weights

Doing the experiment and writing it up
- Create the setup shown in figure 55. If the lever hangs horizontally, it is balanced.
- Hang one weight in hole 4 to the left of the suspension point; the system will then no longer be balanced.
- Balance the lever by hanging weights in hole 1 on the right.

1 Copy table 5 into your exercise book. Write down the number of weights at the appropriate place in the table.

- Remove the weights from hole 1 on the right again.
- Hang weights in hole 2 on the right until it is balanced.

2 How many weights are needed to balance it again?
Write down this number in the correct place in the table.

- Think up for yourself what you need to do to complete the rest of the table.

3 Write down all the results in the table.
4 What rule can you work out from this table? Write the rule down in your own words.

▼ **table 5** the measurement data from experiment 2

left-hand side of the lever	right-hand side of the lever
1 weight in hole 4	… weights in hole 1
1 weight in hole 4	… weights in hole 2
1 weight in hole 4	… weights in hole 4
2 weights in hole 3	… weights in hole 1
2 weights in hole 3	… weights in hole 2
2 weights in hole 3	… weights in hole 3

Experiment 3 Predicting and checking 20 min

Introduction
You can use the law of levers to see whether a lever is in equilibrium or not.

Aim
You are going to use the law of levers to make predictions that you can then check.

Requirements
- stands
- a lever with holes
- 9 weights

Doing the experiment and writing it up
– Once again, you are going to use the lever from figure 55.

– Table 6 describes six situations. Calculate how you can balance each of the situations.

1 Copy table 6 into your exercise book. Write down the number of weights needed in pencil in the table.

– Check your predictions by doing the experiments.

2 Which outcomes did you predict correctly?

– Do a new calculation if necessary for any outcomes you hadn't predicted correctly.
– Check your new results.

3 Now you can fill in the finalised table using a pen.

▼ **table 6** the six situations from experiment 3

left-hand side of the lever	right-hand side of the lever
1 weight in hole 2	… weights in hole 1
2 weights in hole 2	… weights in hole 1
3 weights in hole 2	… weights in hole 1
2 weights in hole 4	… weights in hole 2
1 weight in hole 4 plus 1 weight in hole 2	… weights in hole 3
2 weights in hole 4 plus 1 weight in hole 1	… weights in hole 3

Experiment 4 Pulley and tackle 20 min

Introduction
An object that is much too heavy to lift can easily be hoisted using a block and tackle. You can even do it with objects that have a greater mass than your own.

Aim
You are going to investigate how a fixed pulley and a block and tackle work.

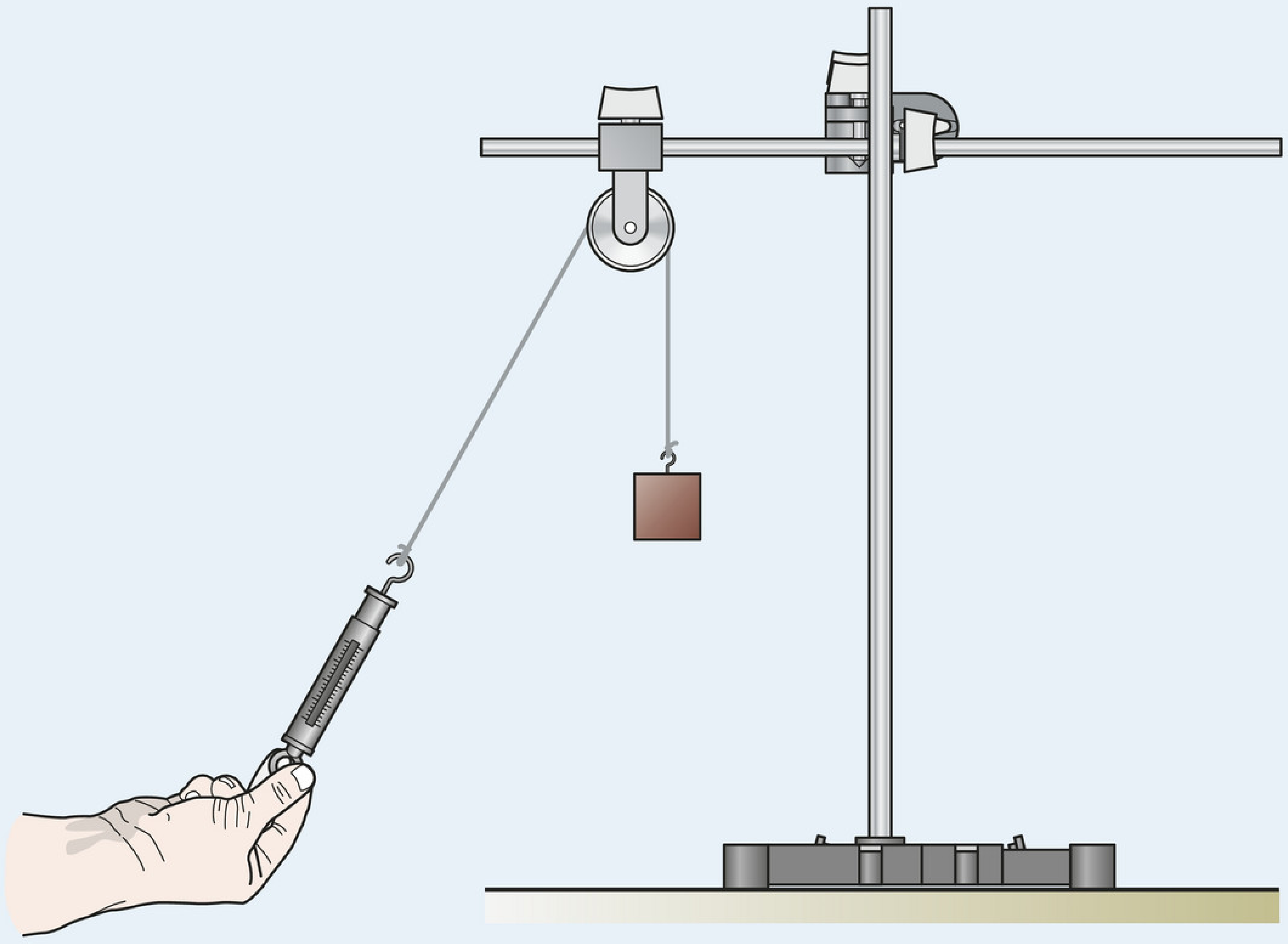
Requirements
- stands
- 2 pulleys
- string
- a mass
- dynamometer
- ruler

Doing the experiment and writing it up
– Measure the force of gravity on the mass by hanging it from the dynamometer.

1 Make a note of the force shown by the dynamometer.

The fixed pulley
– Tie the string to the mass. Then pass the string over the pulley.
– Construct the setup as shown in figure 56.
– Raise the mass *slowly* (!) by pulling the dynamometer down at an angle of 45°.

2 Make a note of the force shown by the dynamometer.



▶ **figure 56**
lifting a block using a fixed pulley

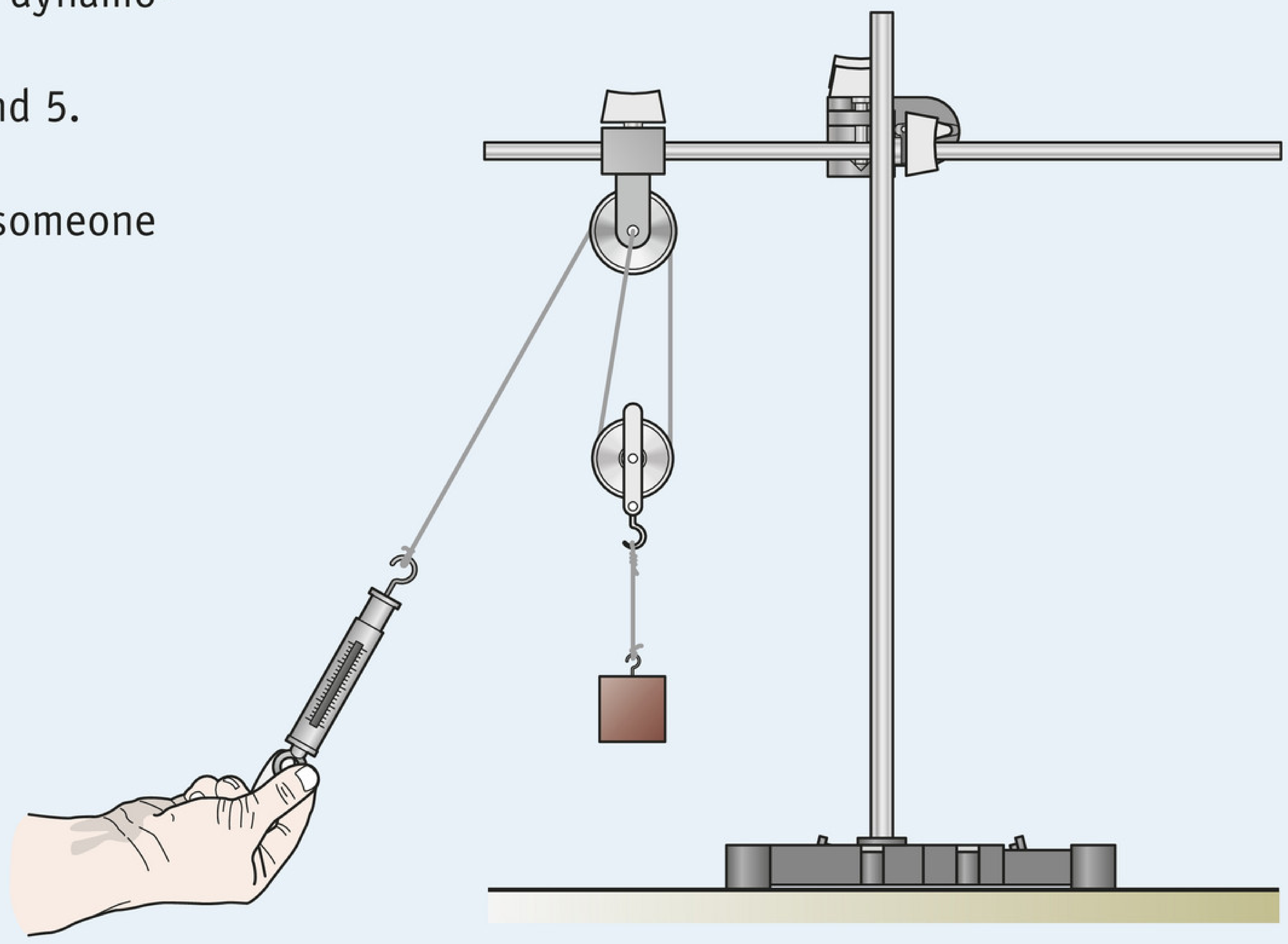
3 Compare the answers to questions 1 and 2. What conclusion can you draw?
4 Can you use a fixed pulley to lift someone who is heavier than you are? Explain.

The block and tackle
– Now construct the setup as shown in figure 57.
– Raise the mass *slowly* (!) by pulling the dynamometer down at an angle of 45°.

5 Make a note of the force shown by the dynamometer.
6 Compare the answers to questions 1 and 5. What conclusion can you draw?
7 Can you use a block and tackle to lift someone who is heavier than you are? Explain.

– Repeat the experiment with the block and tackle. Measure how far you have to pull the string down in order to raise the mass by 25 cm.

8 How many centimetres of string did you have to pull in?
9 How does a block and tackle help (what do you gain)?
10 What disadvantage is there (what do you lose)?



▶ **figure 57**
lifting a block using a block and tackle

Experiment 5 Building and calibrating a dynamometer 45 min

Introduction
Imagine: a factory that makes measuring instruments is going to launch a new model of dynamometer that allows forces to be measured accurately. A helical spring has been chosen for the new meter. Your job is to complete the design by adding an accurate and easily readable graduated scale.

Aim
In this experiment, you are going to be making your own graduated scale. The design requirements are:

Design requirements
- The range of measurement of the dynamometer must be at least 0 N to 1 N.
- The distance between the marks on the graduated scale must represent no more than 0.1 N.
- The dynamometer must be at least as accurate as an 'ordinary' dynamometer.

Requirements
The basic setup has been drawn in figure 58. Make your own list of what you will need.

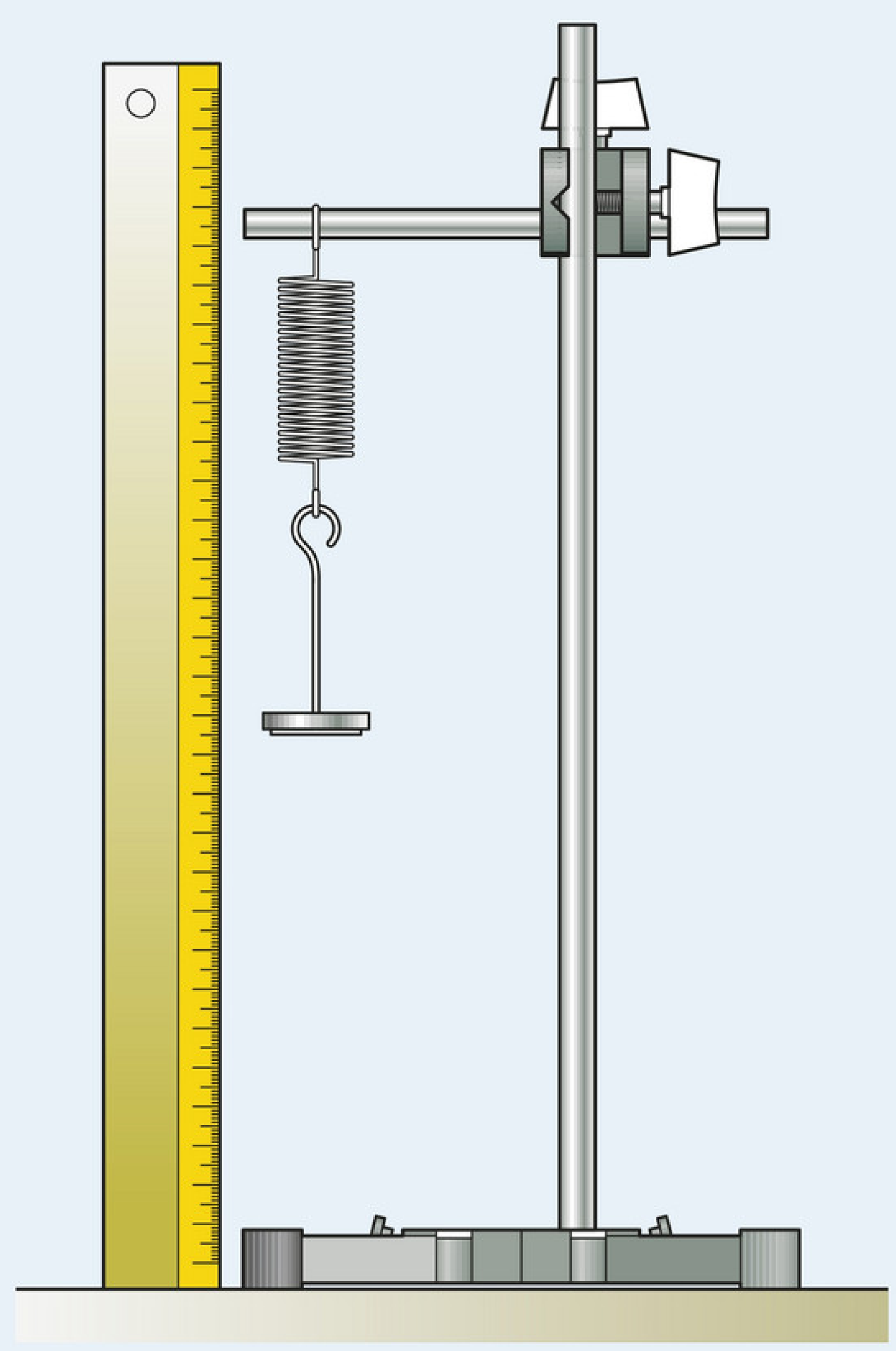
Doing the experiment and writing it up
1 Make a note of the practical equipment you will need.
2 Explain how you are going to calibrate the dynamometer.

- Get your teacher to check the list of practical equipment and the calibration method..
- Construct the dynamometer and give it a graduated scale. Then test whether it meets the three design requirements.

3 Explain how you carried out the test.

- Make improvements if necessary.
- Make a new graduated scale if necessary.
- Finally, get your teacher to assess the dynamometer.

4 Make a report of this experiment, including:
  - **a** a photo of the setup, including the calibrated graduated scale.
  - **b** how you made the graduated scale.
  - **c** the various ways in which you tested the graduated scale.
  - **d** your conclusions. How accurate is the dynamometer?



▲ **figure 58**
the setup for experiment 5

Test Yourself

You can also do questions 1 to 16 on the computer.

1 For each situation, state whether the deformation is elastic or plastic.
- **a** A gymnast pushes off powerfully from a trampoline.
- **b** A tree bends in a strong gust of wind.
- **c** A tractor leaves deep furrows behind on a wet field.
- **d** Tom dents his car quite badly.

2 Two ring magnets are placed on an aluminium rod. The upper magnet then floats above the other (figure 59).
- **a** What two forces are acting on the upper magnet?
- **b** What can you say about the magnitudes of these two forces?
- **c** What can you say about the directions of these two forces?
- **d** Is the upper magnet weightless?
- **e** Did the weight of the lower magnet change when the second magnet was placed on the rod?

▶ **figure 59**
an experiment with two ring magnets

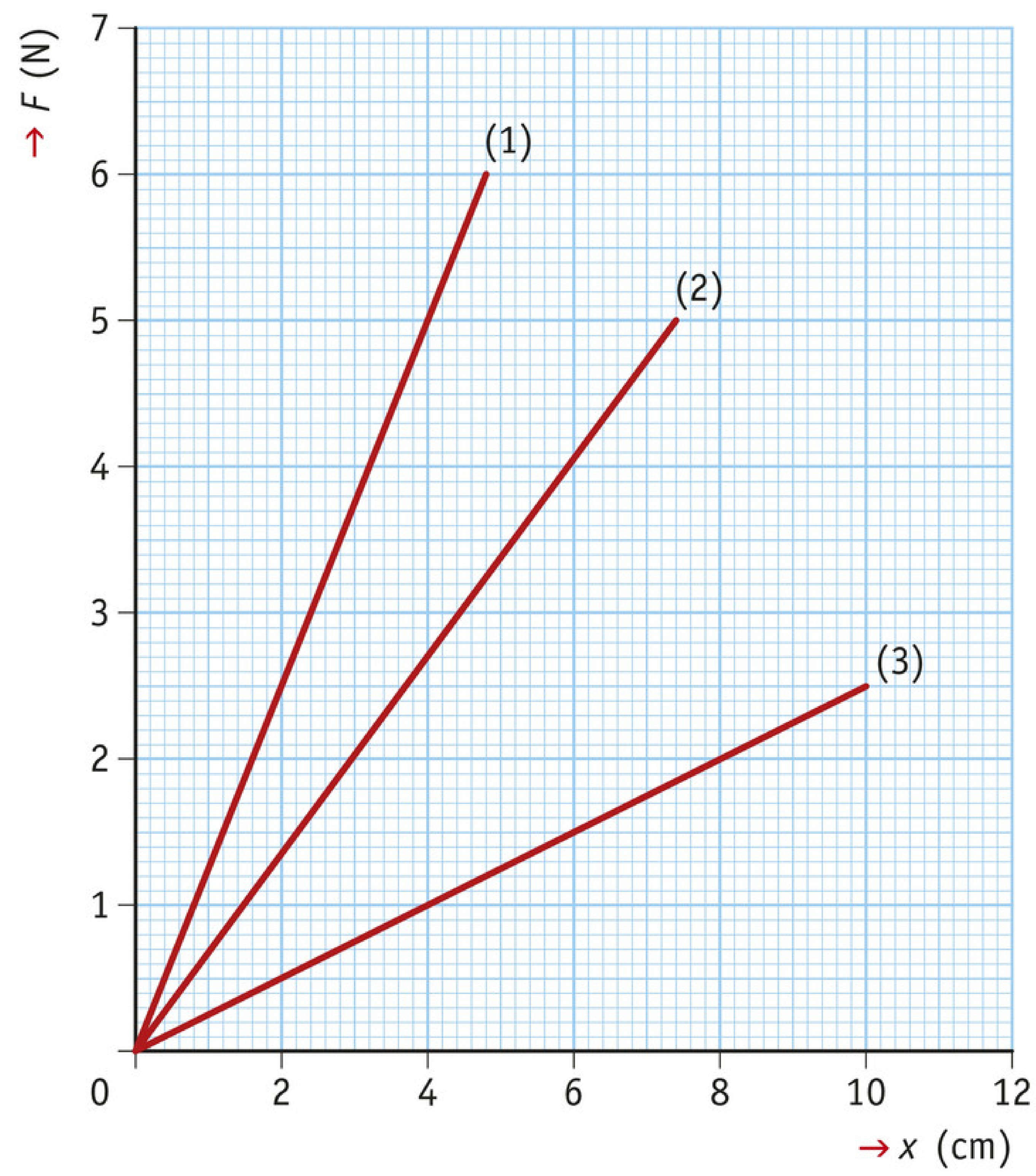
3 An importer of forklift trucks says the following on its site:

Linde H25D-02 forklift Capacity 2500 kg Weight 4470 kg

What is the force (in kN) that the forklift exerts on the floor when it is fully loaded?

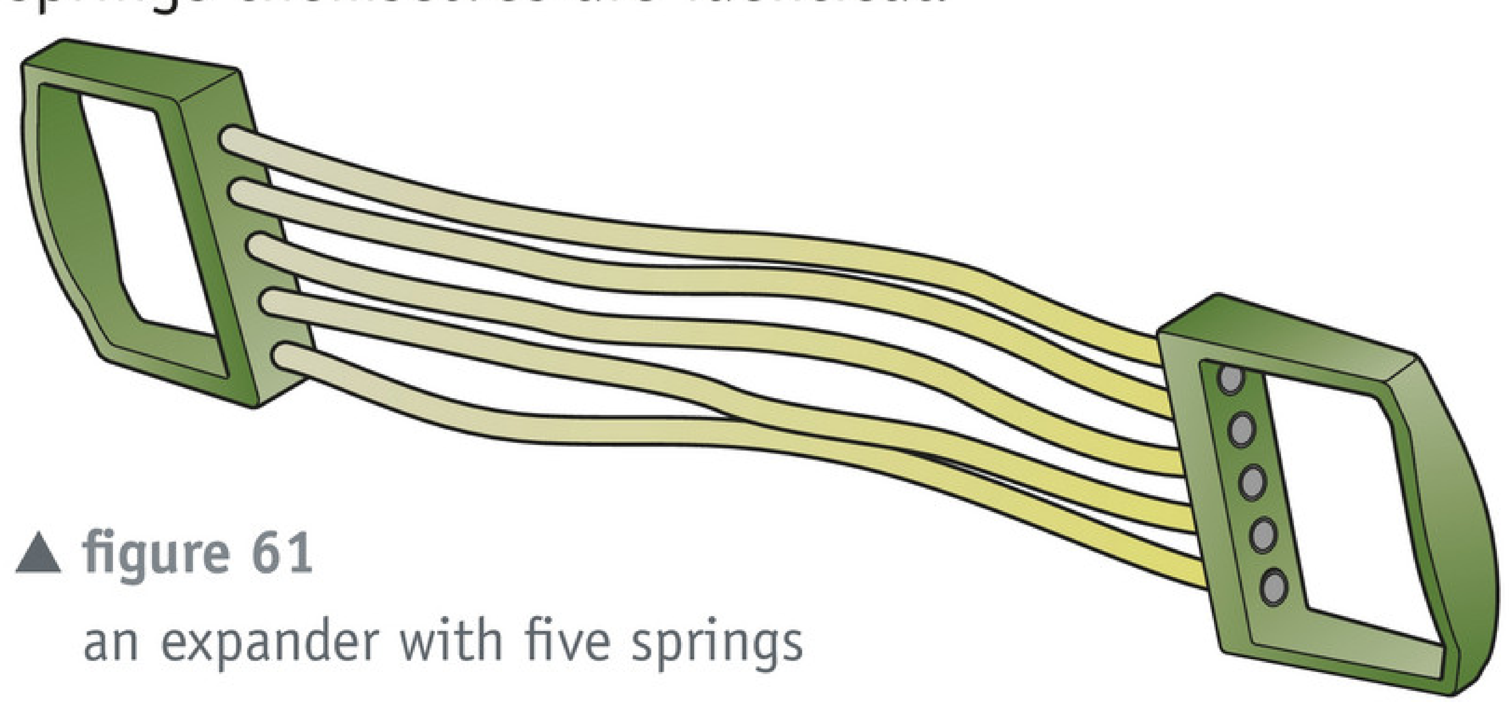
4 Before you can draw a force, you first need to decide on a force scale.
- **a** Gillian chooses a force scale of 1 cm ≙ 20 N. How long is the arrow she must draw to represent a force of 84 N?
- **b** Luke draws a force of 240 N as an arrow that is 4.8 cm long. What force scale has he used?

5 For three springs 1, 2 and 3, Nikki has measured how far they extend when she hangs weights on them. Figure 60 shows you the graph of this experiment.
- **a** Which spring is stiffest?
- **b** What is the spring constant of this spring?



▲ **figure 60**
Which spring is stiffest?

6 The expander in figure 61 has a spring constant of 900 N/m if you try to stretch all its springs at once.
What is the spring constant of a single spring? The springs themselves are identical.



▲ **figure 61**
an expander with five springs

7 A family are having a tug-of-war contest. Paul (the father) and Inez (the daughter) are up against Martina (the mother) and Barry (the son). Paul is pulling with a force of 620 N, Martina with a force of 480 N and Inez with a force of 250 N. What pulling force does Barry have to apply if the rope is to be kept in equilibrium?

8 State whether each of the following statements is true or false.

a The Earth is by far the largest of the eight planets in our solar system.
b The orbit that a planet takes around the Sun is an ellipse.
c In that motion, gravity provides the centripetal force.
d Gravity acts in the same direction as the motion of the planets.
e While people or objects are in freefall, they have no weight.

9 The globe in figure 62 (diameter 26 cm) is a scale model of the Earth (diameter 13,000 km).
What would the distance between the Earth and the Sun (150 million km) be if it was represented using the same scale?

A 3 m
B 30 m
C 300 m
D 3 km
E 30 km

▶ **figure 62**
A globe is a scale model of the Earth in three dimensions.

10 Garfield is standing on the scales on one leg.
The scales say 60 kg.
Which of these statements is correct (strictly scientifically)?

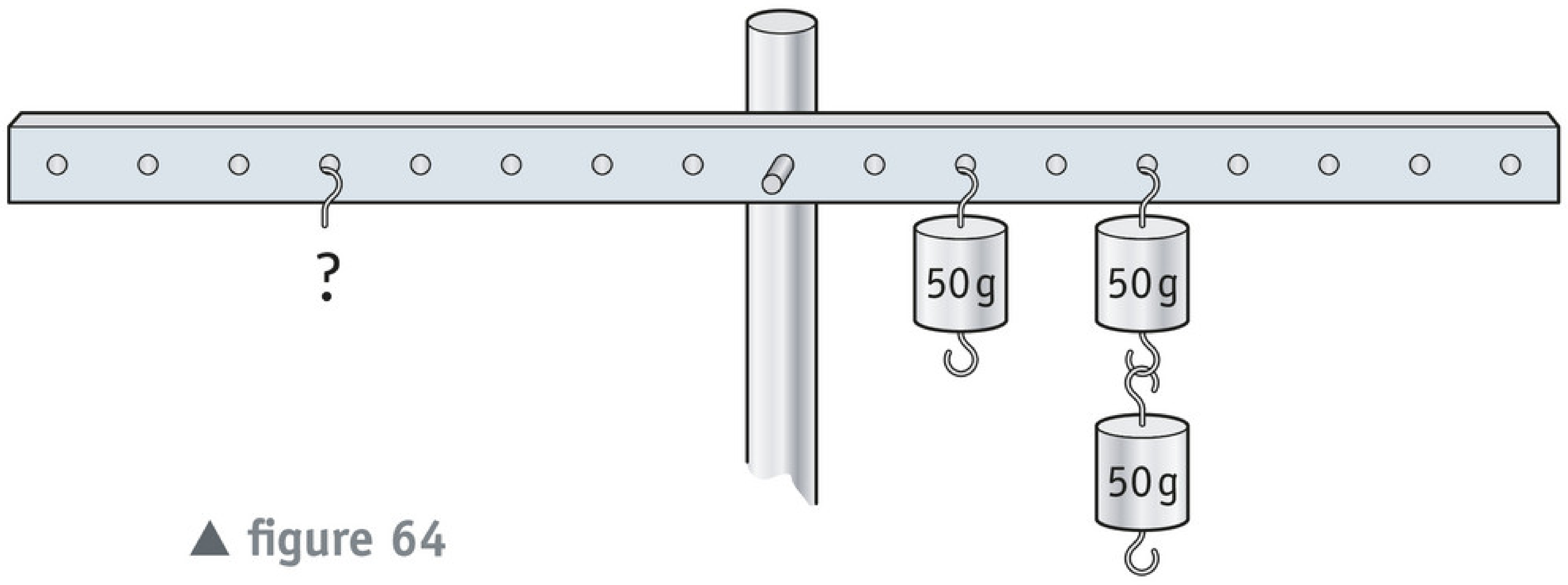
A Garfield's weight is 60 kg.
B Garfield's weight is 600 N.
C Garfield's weight is 300 N.
D Garfield is completely weightless.

11 Matthew is putting a full container of rubbish out on the street (figure 63). The force of gravity on the container and Matthew's muscular force are balanced. Holding the container as shown on the photo lets you make:

A the moment of the muscular force as small as possible.
B the moment of the force due to gravity as small as possible.
C the moment of the muscular force as large as possible.
D the moment of the force due to gravity as large as possible.

◀ **figure 63**
Matthew is putting the bin out.

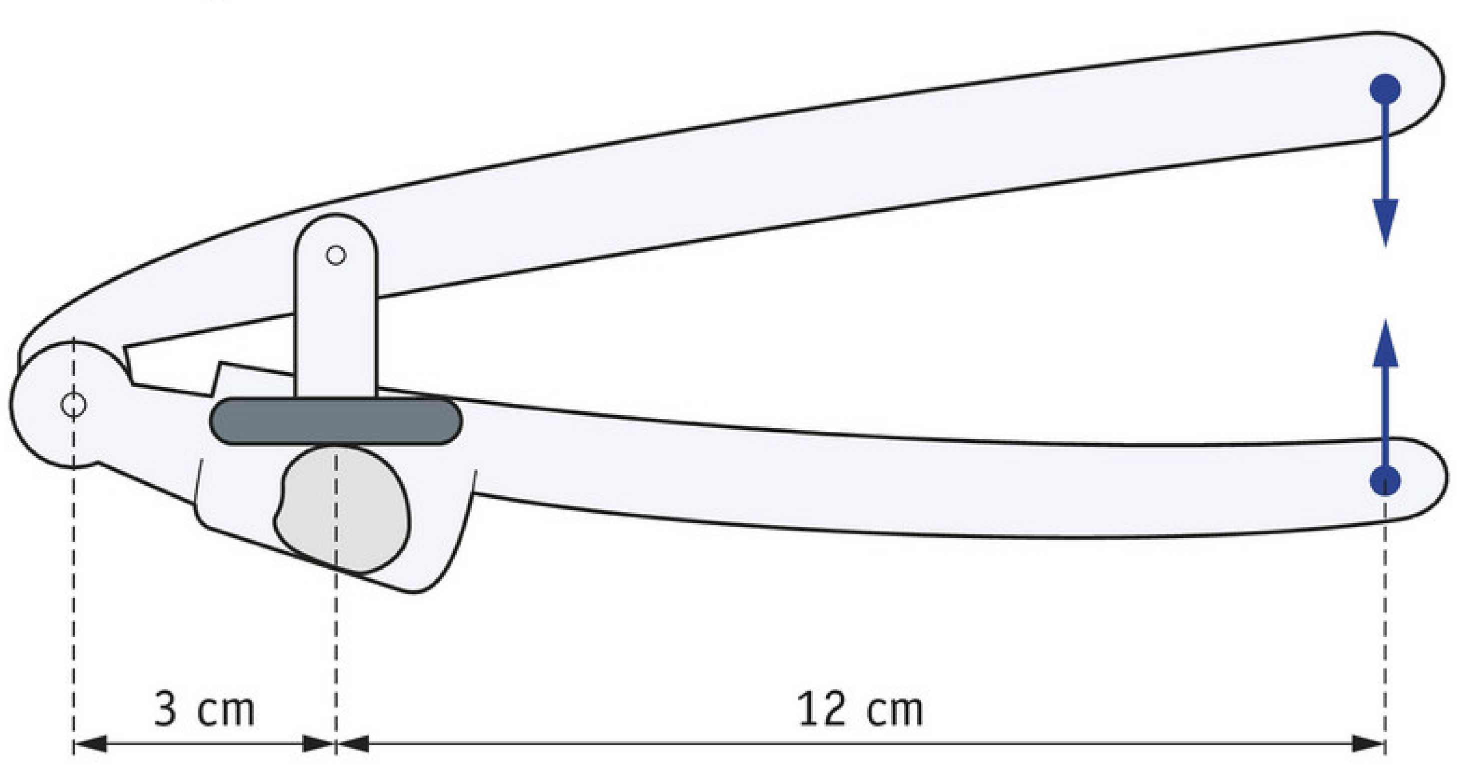
12 Irina has set up a practical experiment with a lever (figure 64). At the point indicated on the left, she wants to hang more weights so that the lever is in equilibrium.
Calculate what the mass of that weight/those weights must be.



▲ **figure 64**
a lever with weights

13 The garlic press in figure 65 is used for crushing garlic cloves finely.
When you squeeze the handles together, the force on the clove of garlic is:

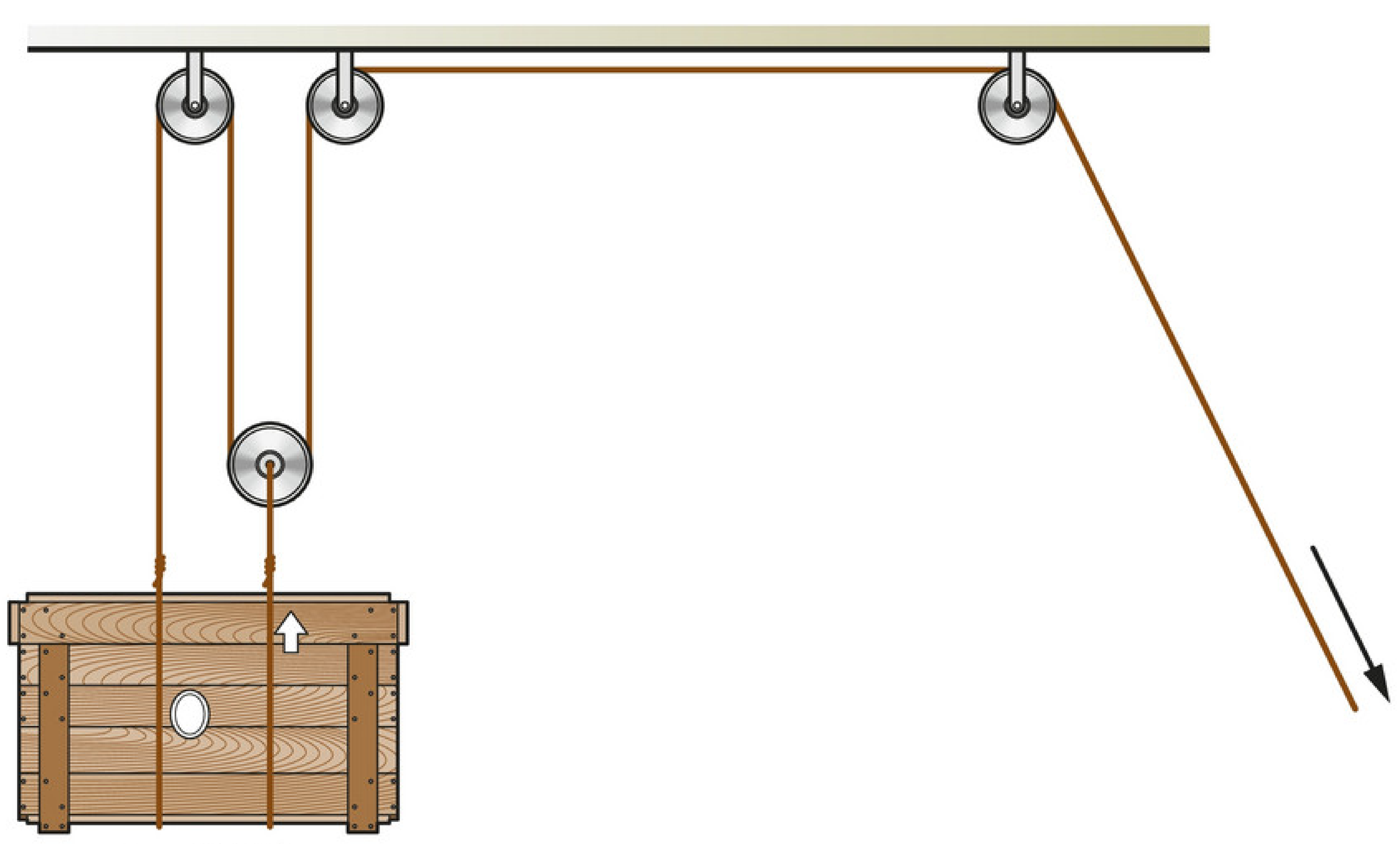
A 4× greater than the muscular force.
B 5× greater than the muscular force.
C 3× greater than the muscular force.
D 9× greater than the muscular force.



▲ **figure 65**
a garlic crusher

14 A block and tackle makes the hoisting force *N*× greater than the pull exerted on the rope.
How big is the number *N*:
a in a block and tackle with one fixed pulley and one loose pulley?
b in a block and tackle with three fixed pulleys and three loose ones?

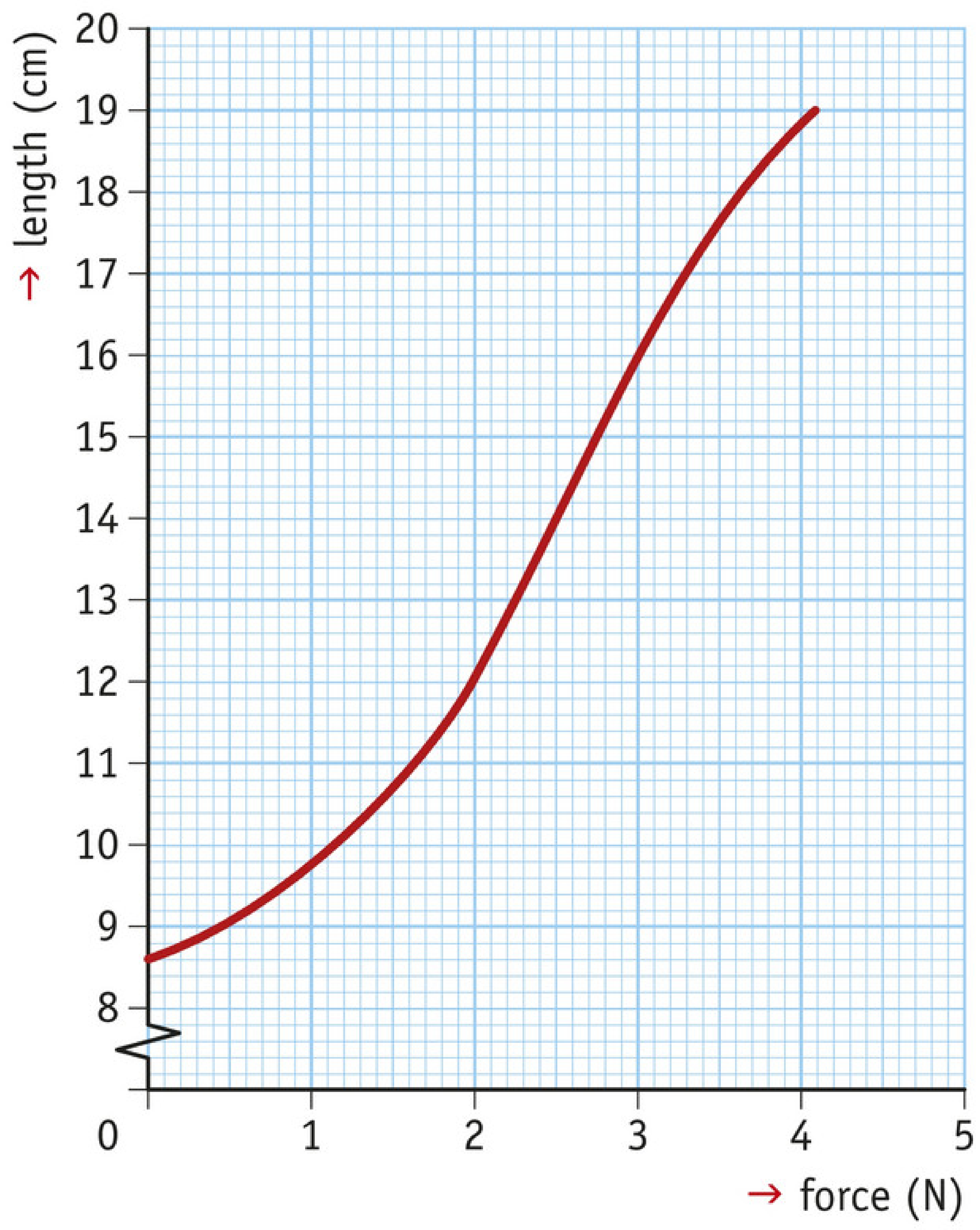
15 Figure 66 shows you how a crate of 150 kg is being hoisted using a number of pulleys. The mass of each pulley is 5.0 kg.
a What pulling force is required on the rope? Round off your answer to a whole number.
b The crate has to be lifted 6.0 m.
How many metres of rope have to be hauled in in order to do that?
c How much work have you then done?



▲ **figure 66**
hoisting with a block and tackle

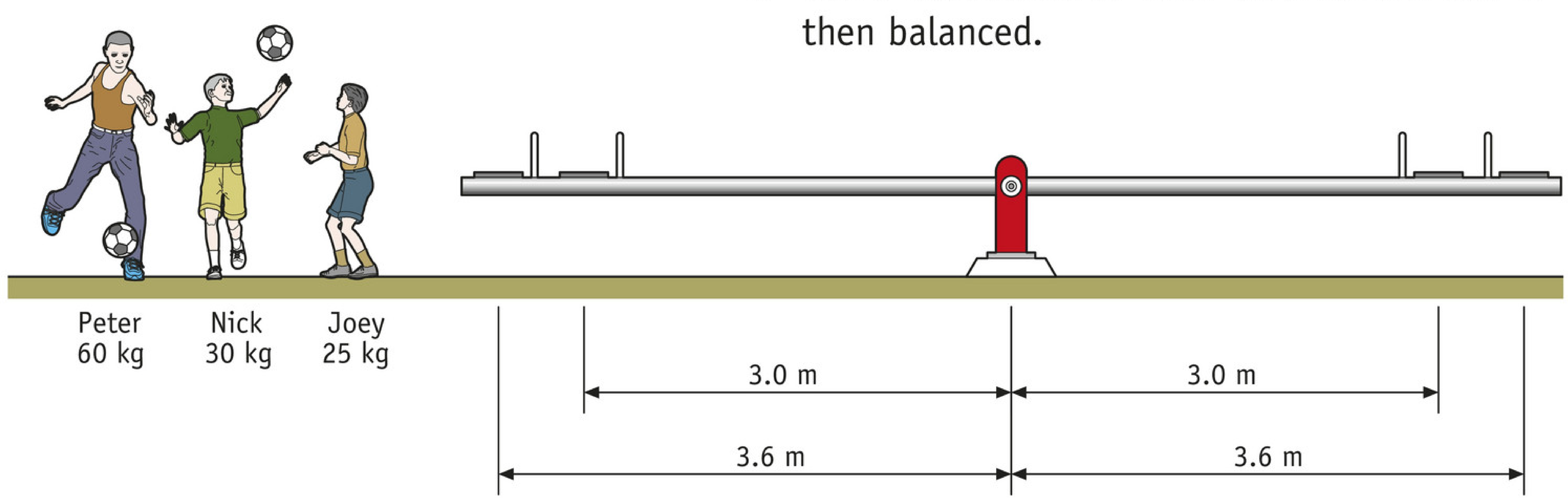
16 You need worksheet 1-9 for this exercise.
On the worksheet, you can see how Dennis is keeping a chair of 3.2 kg balanced with one hand.
a What forces are acting on the chair?
b How large are these forces?
c On the worksheet, show the line that the chair's centre of gravity must lie along.

17 Georgina has done an experiment with an elastic band. You can see her measurement results in figure 67.
a How long will the rubber band get if you hang a pencil case weighing 200 g from it?
b If a pair of scissors is hung from the rubber band as well as the pencil case, the length is 16 cm.
How long would the rubber band be if you only hung the scissors on it?
c You slowly increase the pulling force applied to the rubber band from 0 to 2 N.
Does the elastic band then get more and more stiff or increasingly stretchy?



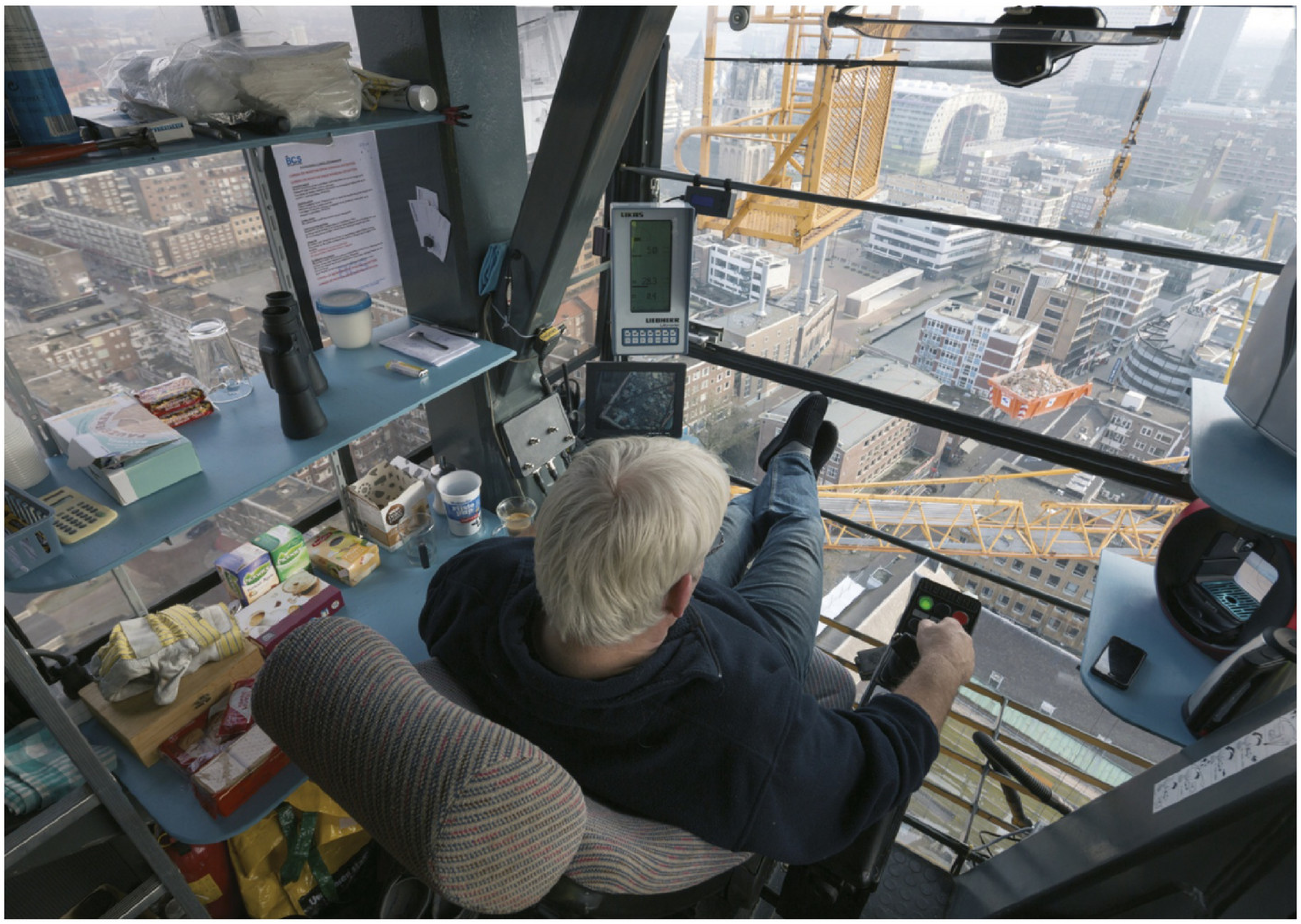
▲ **figure 67**
the force-extension diagram for a rubber band

18 Figure 68 shows you a see-saw with three children on. You can place the children on three of the four seats so that the see-saw is balanced.
a State where each of the children then has to sit.
b Use a calculation to show that the see-saw is then balanced.



▶ **figure 68**
What combination is balanced?

Tower cranes: the art of balance at great



The cab is small, but the view is breathtaking. Arno, a crane operator enjoys it every day. "Particularly in the morning when the Sun's coming up. That's always beautiful, no matter how many times you see it," he says. Not that he has much time to look around. "Work comes first," he says. "In the construction industry, everyone is really bothered about safety, and as a crane operator, you have to be even more alert. You must never forget that there are people working down there, underneath your crane."

The Potain MD 560B

Arno's crane is a 560B made by a French company called Potain. This is the data from the manufacturer:

Technical data

power	120 kW (hoisting motor 94 kW)
connection voltage	400 V
lifting capacity	25,000 kg
rotation speed	max. 0.7 rev/min
load moment	max. 500 ton-metres
jib length	35 to 80 m
hook height	max. 78.6 m

heights

Every day, a tiny lift cage takes Arno to his place of work, high up in a tower crane. He uses buttons, handles and pedals to lift construction materials and puts them down in the correct places. "Hoisting is teamwork," he says, "even if you are up there in the cab on your own. The walkie-talkie keeps me in touch with my colleagues down below. They also use gestures to give me instructions."

Over the last six months, Arno has seen the tower block he is working on keep growing upwards, and his crane has been growing, along with the building. Every now and then, the mast has to be made taller by adding an extra section. Arno started out 50 metres up, but now he is up at 80 metres. From there he can look down on the roof of the tower block, about 15 metres beneath his cab.

Balancing

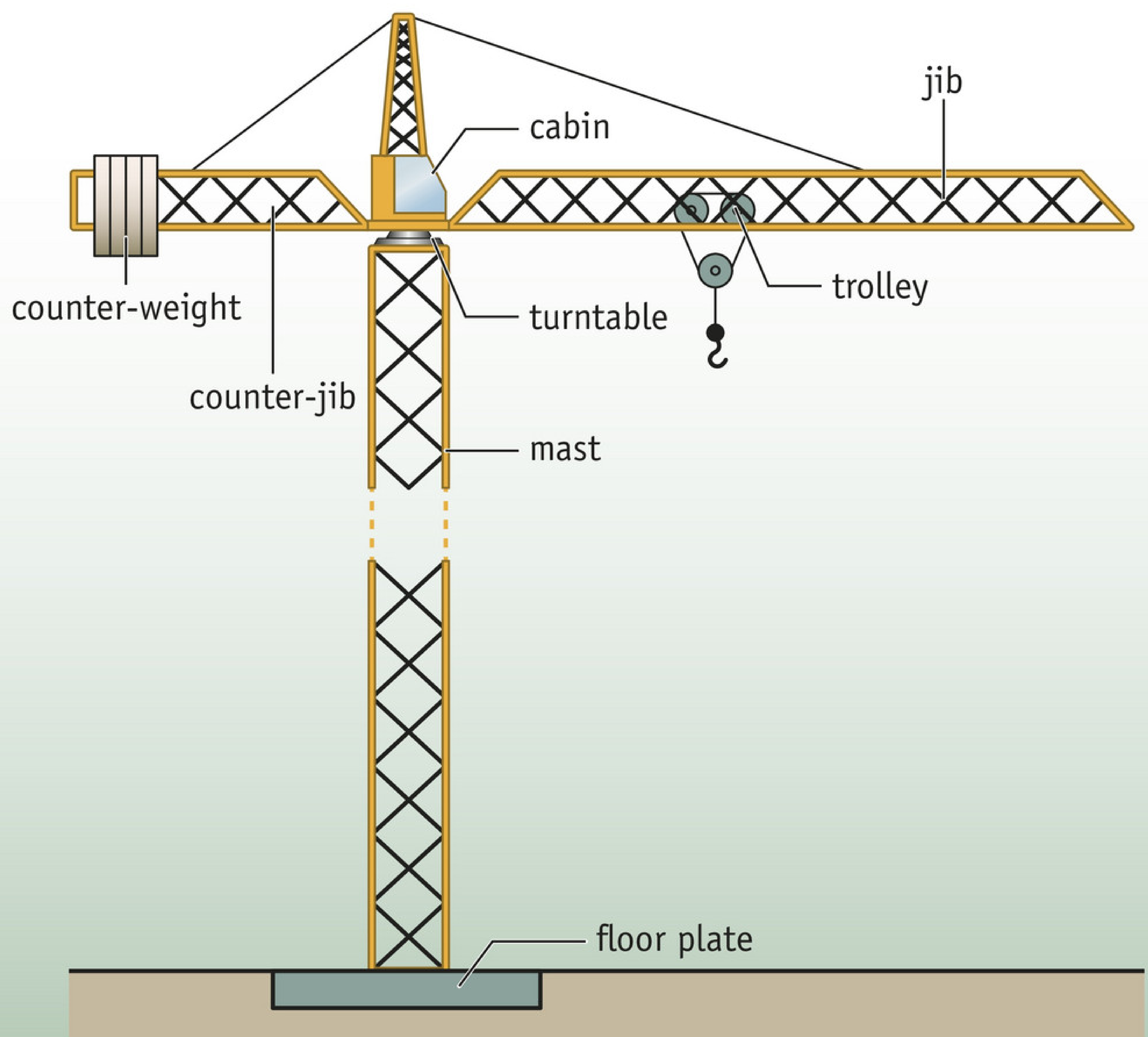
The jib of Arno's crane – the long arm with the hoisting equipment on – is 65 metres long. A 'trolley' moves back and forth along the boom (or jib). The hoisting cables, the pulley and the hoisting hook are attached to it. These are used for lifting and positioning the load. The counter-jib – the arm on the other side of the cab – is much shorter. A counterweight made of large blocks of concrete hangs from it.

When there is no load on the crane, the moments on the longer arm and the shorter one are equal. The crane is then balanced. That changes when the crane lifts a load. The moment on the longer arm then increases and the original equilibrium is unbalanced. The reason why the crane does not fall over is because it is anchored securely in a heavy concrete plate.

"At the point when the load is lifted off the ground, you can feel the crane wobbling."

That provides a moment that counteracts the change and quickly restores the balance.

It always takes a couple of seconds before the crane is properly balanced again. Arno knows that all too well. "At the point when the load is lifted off the ground, you can feel the crane wobbling. At first, it took me a while to get used to it. You realise that it would be perfectly possible to lose the balance at that moment. After all, it's not exactly a bag of feathers that you've got hanging from it there."



How can you make a crane taller?

To make a tower crane taller, separate mast elements are used. The crane itself hoists the mast element up. The whole of the top of the crane, including the boom and the counter-jib, is then jacked up hydraulically. Finally, the new mast element is inserted into the space that this has created and it is fixed in place. The crane is then ready for the next phase of the construction.

If there's any doubt: look in the hoisting table!

Arno's crane can lift a great deal. If necessary, it can lift 25 tons in one go. "But that's only possible if the load isn't too far from the mast. The maximum then is 20 metres," he explains. "If the distances are bigger, the moment of the load

jib length	maximum length for a flight of						
	20 m	30 m	40 m	50 m	60 m	70 m	80 m
80 m	25.0 t	16.8 t	12.2 t	9.3 t	7.4 t	6.0 t	5.0 t
65 m	25.0 t	18.0 t	12.9 t	10.1 t	8.1 t		
50 m	25.0 t	19.0 t	13.6 t	10.7 t			
35 m	25.0 t	19.8 t					

becomes too much and the crane isn't built to take it. The safety limit is at 25 tons × 20 metres = 500 ton-metres. That's what they call the maximum load moment."

When Arno is working, he therefore has to keep an eye on two things: the size of the load and the length of the 'flight' (the term crane operators use for the distance the load is from the mast). If the load is small, he *can* choose a larger flight. But if the load is heavy, he *must* keep the flight small. Otherwise there is a risk that the boom or the mast might suddenly bend or break.

Every crane has a hoisting table. The operator can use it to see what the maximum flight is for a given load, or vice versa. A simplified version of Arno's hoisting table is shown above. The real hoisting table looks much the same, although it is in much more detail. If Arno has to lift a load of 10 tons, he first looks up the jib length in the table. "The jib is made up of separate elements that are all connected together," he explains. "So the maximum length of the jib is in fact calculated beforehand for each job. For this job, it is 65 metres." The table states that a maximum of 10.1 tons can be hung from the hook for a flight of 50 metres when the boom is 65 metres long. "With the 10 tons I've got now, I'm just inside the limit." says Arno, "so I can put the load down 50 metres away from the mast."

Safety comes first

As a crane operator, Arno is responsible for safety. "That's number one for me," he says decidedly. "Fortunately there aren't many accidents with tower cranes. But it only has to go well and truly wrong just once and you immediately have serious problems. So you always have to know exactly what you're doing. You can't just improvise in this job."

Luckily there have been various developments to improve safety. Cameras show the operator exactly what is happening way down below. Electronic systems raise the alarm if the load or the load moment is too great. But the operator himself remains the most important link in the safety chain. Or, as Arno himself puts it, "All that technology in the cab is wonderful. But it's still no help if you've got some nutter operating the levers. The most important balance is the one between your ears."

Exercises

1 Some cranes have a counterweight than can be moved back and forth along the counter-jib.
Explain:
- **a** what the benefit is of having a movable counterweight, as opposed to a 'fixed' counterweight.
- **b** why the counterweight does not have to be moved if the load is hoisted up vertically.
- **c** why the counterweight does then move if the distance between the load and the mast is altered.

2 Search the Internet for more information about hiring mobile cranes for hoisting.
- **a** Think up a realistic hoisting job. Make a note of the load (in kg) and the flight (in m).
- **b** Calculate what the maximum load moment of your 'rental crane' would need to be.
- **c** Find a rental company on the Internet that has a suitable crane for this job. Make a note of the crane that you have chosen and explain why this is a suitable choice.

***3** Study the hoisting table in the text.
- **a** What effect does the jib length have on the maximum load that can be lifted (for a given flight)?
- **b** Why does the jib length actually have an effect on the maximum load? Use the concept of a 'moment' in your explanation.

2 Electricity

Using electrical energy

You cannot live without electricity. You will soon realise that when there is a power cut. Lighting and heating go off and all kinds of appliances stop working. Many people cannot do their work anymore. That is why everyone is very glad when the lights come on again.

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1 Transporting electrical energy

▲ figure 1
the Amer power station in Geertruidenberg

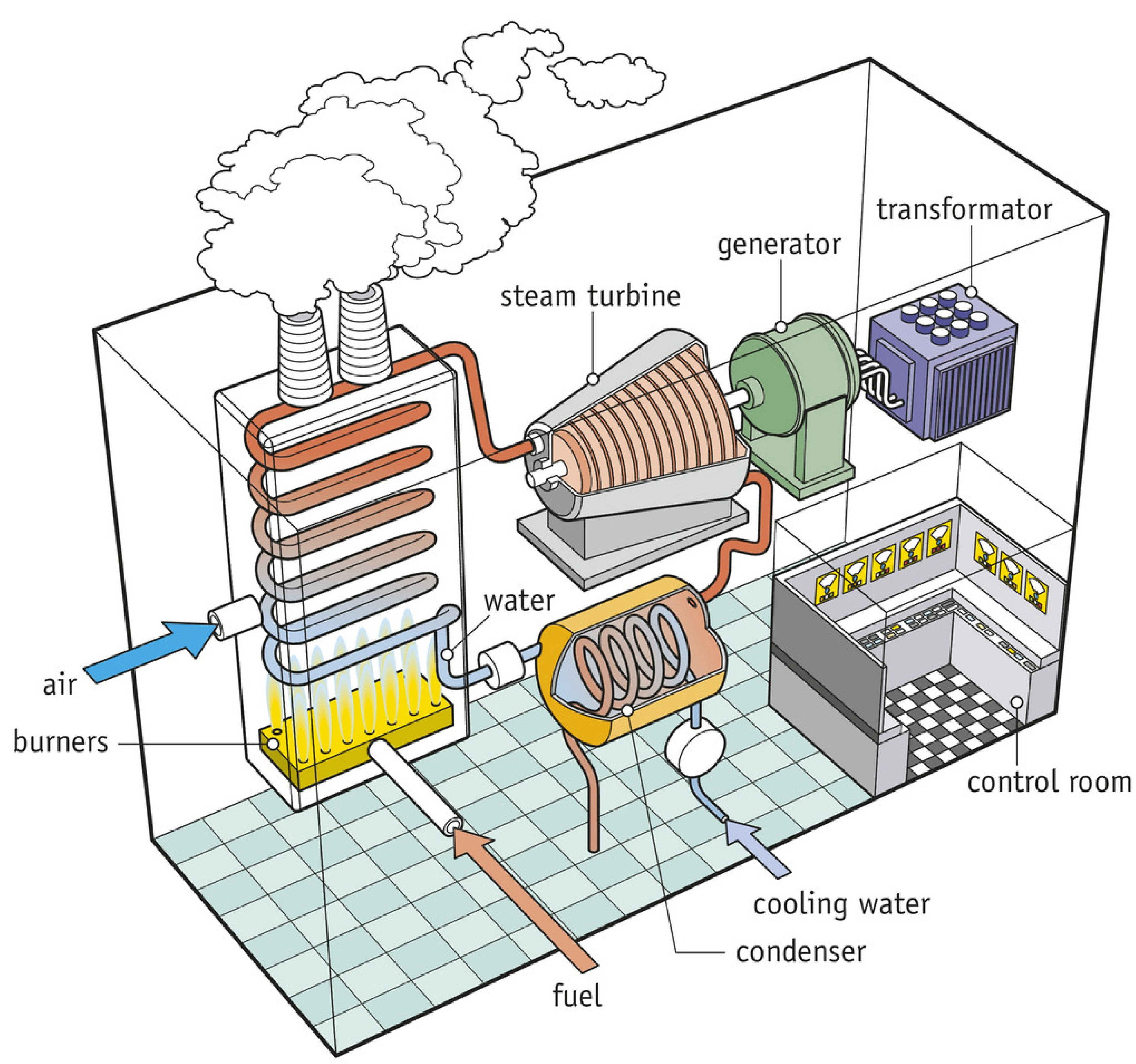
An extensive distribution system transports the electrical energy that you need from the power station to your home. The voltage is transformed up and down several times during this transport.

The power station

The electrical energy that you use at home may have been generated in various ways: by a conventional **power station**, a nuclear power station, by a wind turbine, or by a panel of solar cells. In the Netherlands, conventional power stations still provide most of the energy at the moment, although this may change in the future (figure 1).

Figure 2 shows how a conventional power station works:

1 The **burners** burn natural gas, coal or another fuel. The heat that is released heats up the water in the boiler. This creates steam – hot water vapour – at a temperature of approximately 500 °C and a very high pressure.
2 The steam passes the blades of a **turbine** at high speed. This makes the shaft of the turbine rotate.
3 A **generator** – a kind of large dynamo – is connected to the shaft of the turbine. Electrical energy is generated in the generator when the turbine shaft rotates.



▶ figure 2
This is what a power station looks like on the inside.

4 The 'waste' steam, now at a much lower temperature and pressure, is discharged into a **condenser**. There, the steam condenses back into (liquid) water. After that the water can be pumped back into the boiler.

In a condenser, coolant water is used for condensing the steam. The cooling water is usually taken from a river or lake. The cooling water is used again and again at locations where there is not enough open water. The power station then has **cooling towers**, in which the cooling water gives off its heat to the outside air (figure 3).

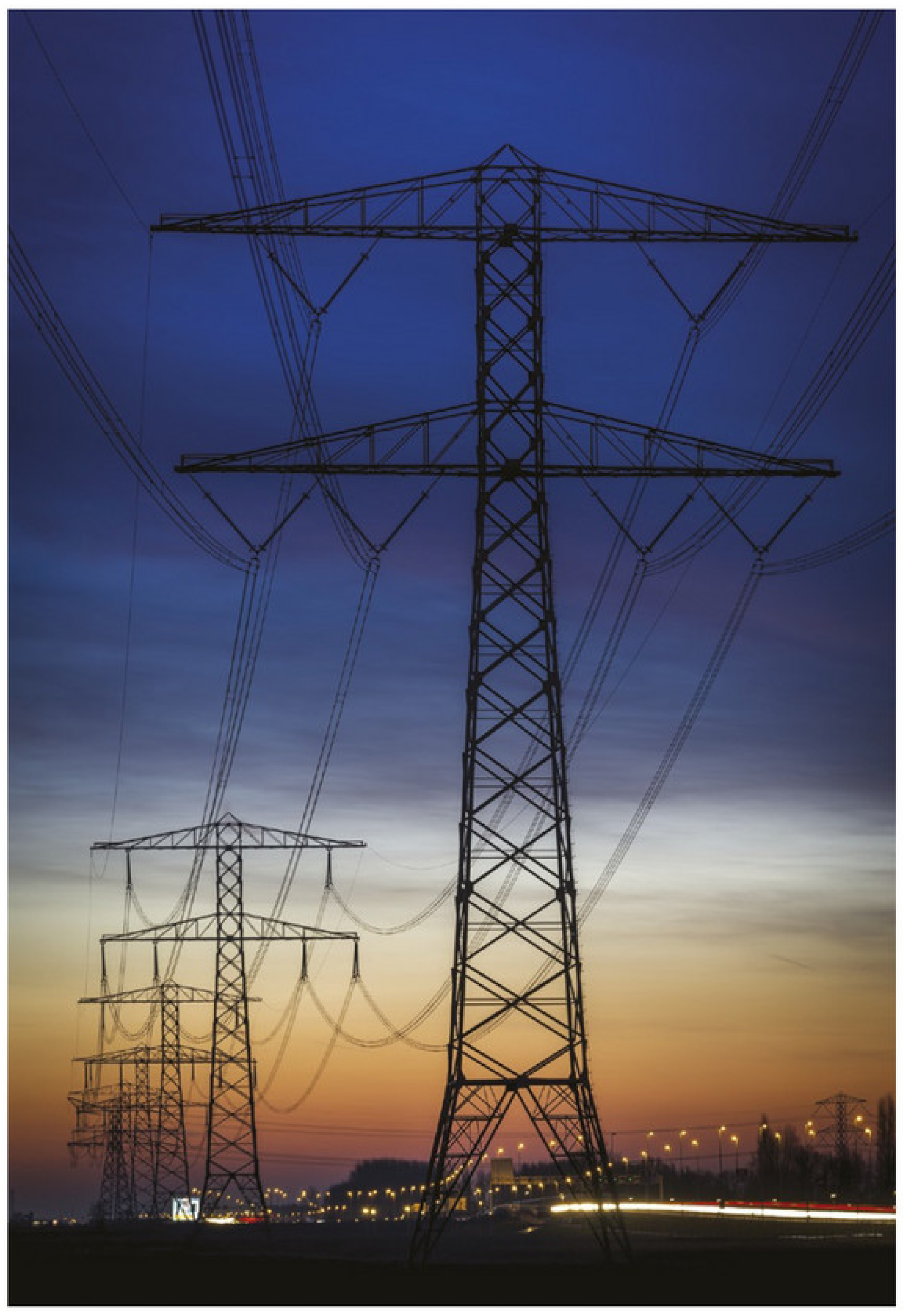
▶ **figure 3**
the cooling towers of the Claus power station near Maasbracht

The electricity grid

When an electric current goes through a cable, the cable will get warmer. This is because part of the electrical energy gets converted into heat. This causes **energy loss**: there will be less electrical energy left for the end users.

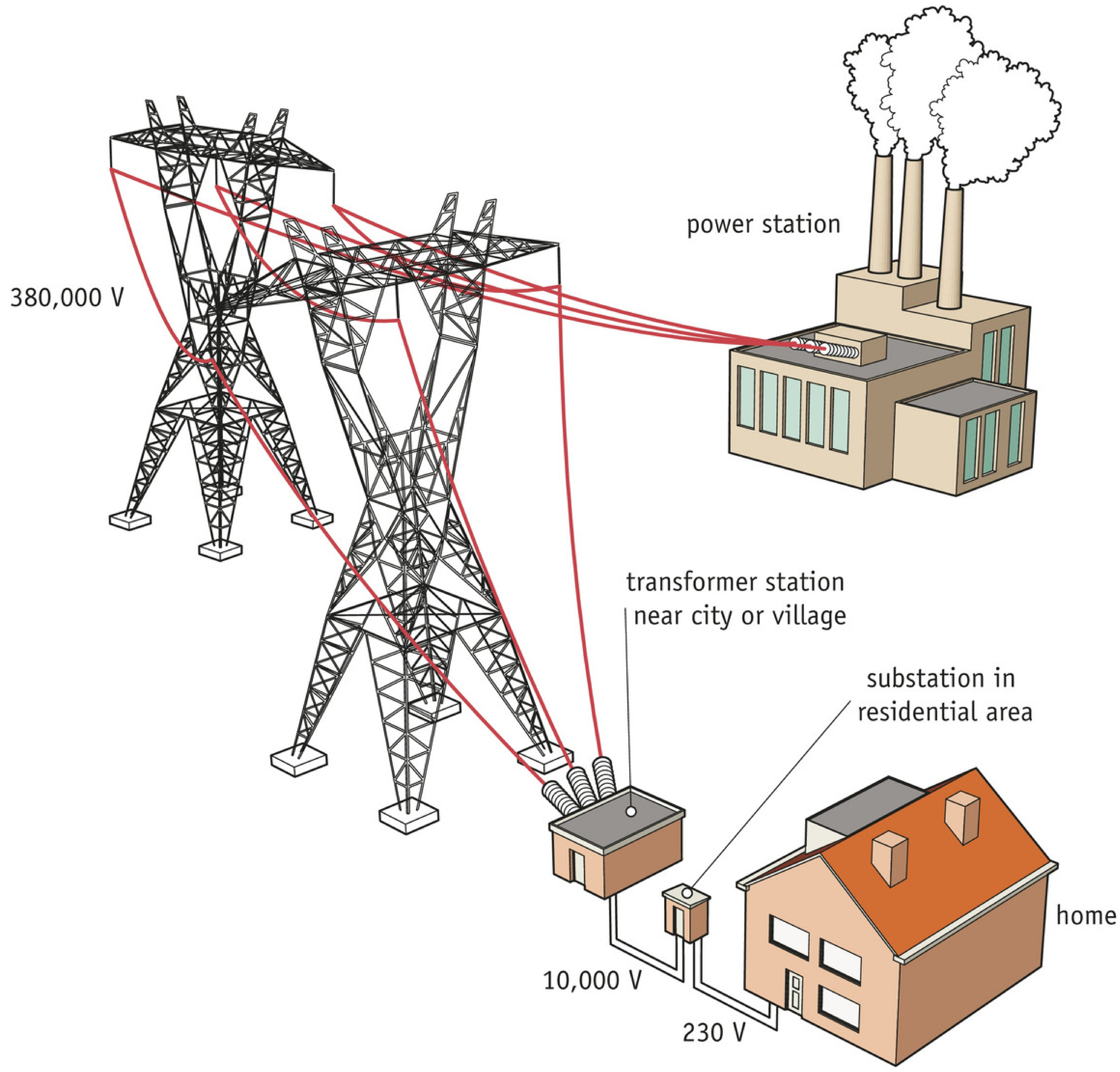
To limit energy losses, electrical energy is best transported at the highest voltage possible. If the voltage used in transmitting the electricity through the power lines is high, both the energy loss and the heat produced are reduced.

That is why the voltage provided by the generators is transformed upwards at the power station. For long-distance transport, the Netherlands uses **high-voltage** lines at 380 kilovolts (kV). High-voltage power lines above ground transport the electrical energy to various distribution stations (figure 4). There, the voltage is transformed down to 10 kV. After that, the electrical energy is transported to residential areas and industrial sites using underground cables.



▲ **figure 4**
High-voltage pylons transport electrical energy at a high voltage.

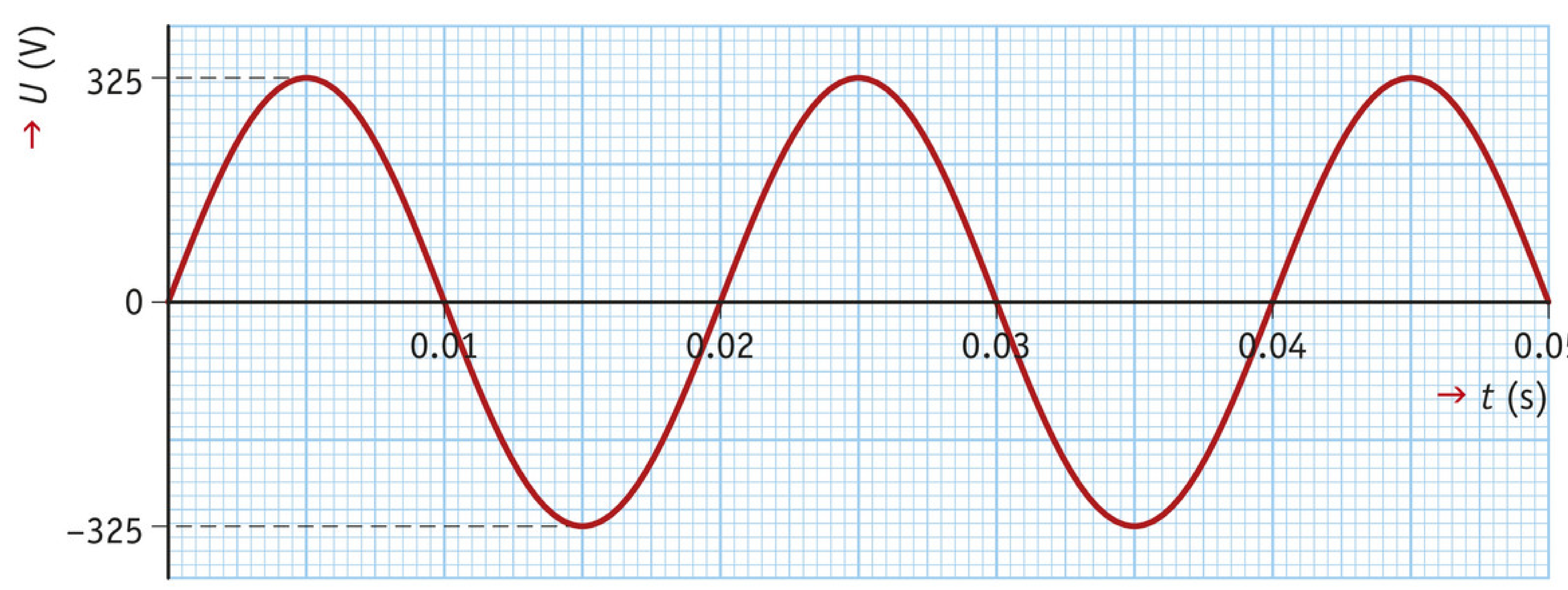
Each residential area has one or more transformer substations (figure 5). There the voltage is transformed down to the **mains voltage** of 230 V before the electrical energy is transported to the homes.



▶ **figure 5**
The electricity grid takes electrical energy from the power station to the end users.

Mains voltage

The mains supply does not provide a continuous **direct voltage** (or **DC voltage**) like batteries do. In fact, the voltage of the mains is rising and falling continuously in a pattern that is repeated fifty times a second. From 325 V via 0 V to –325 V and up again to 325 V (figure 6). It is an **alternating voltage** (or **AC voltage**) with a frequency of 50 Hz.



▲ **figure 6**
an alternating voltage of 50 Hz

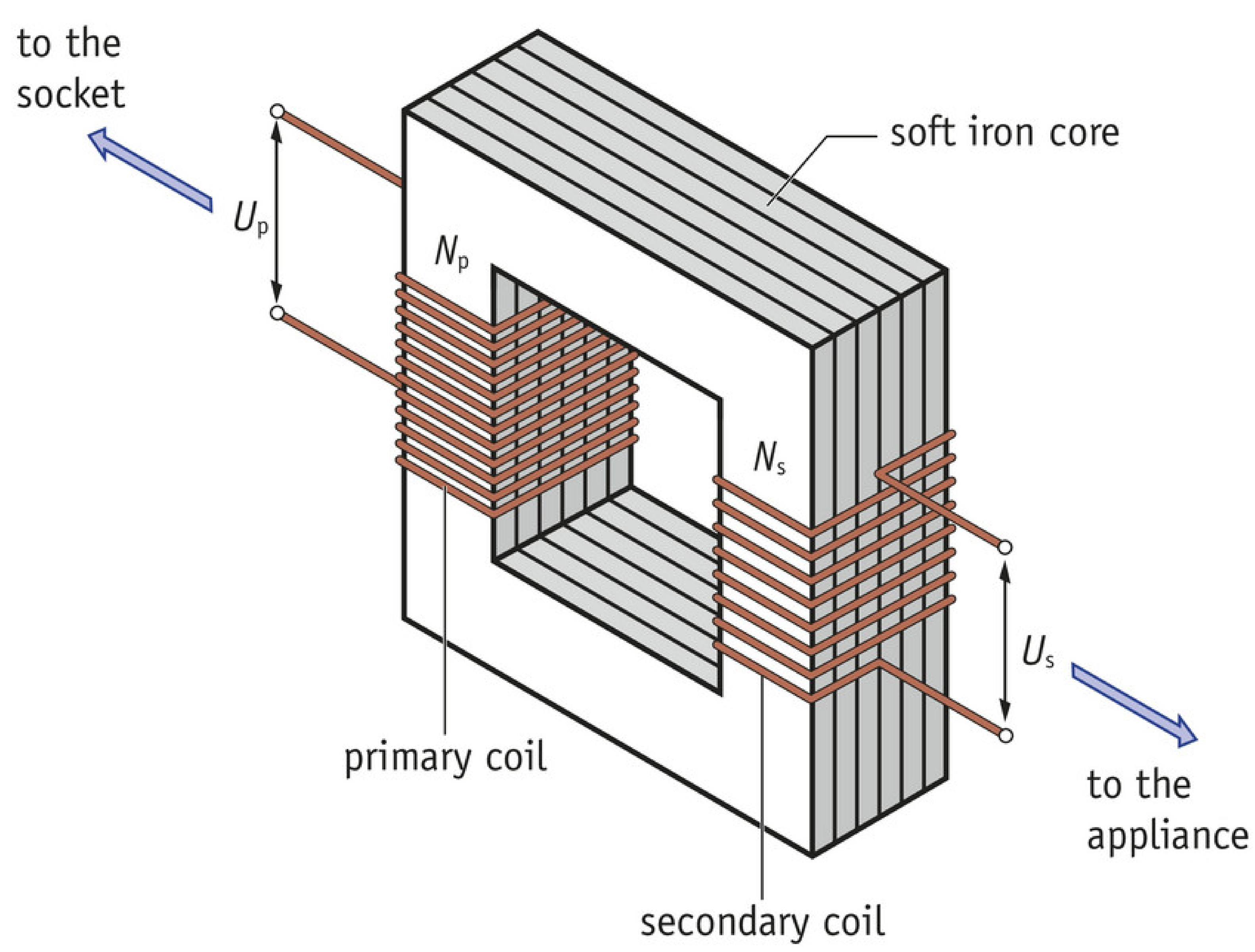
For many appliances, it makes no difference whether they are supplied with the AC voltage of the mains or a direct voltage of 230 V DC. For instance a kettle produces the same amount of heat in both cases.
We therefore say that the **effective voltage** of the mains is 230 V. The word 'effective' is often left out in practice and we just say that the mains supply is 'a voltage of 230 V'.

The voltage of the mains is still too high for some electrical devices, such as a doorbell or a desk lamp with a halogen bulb. These types of devices then need a transformer that reduces the voltage even further.

How a transformer works Experiment 1

A simple transformer that is used in homes has been drawn in figure 7. The device consists of two coils of insulated copper wire around a soft iron core. The **primary coil** is connected to the mains and the **secondary coil** is connected to the appliance.

- When the transformer is being used, an alternating current will go through the primary coil. The primary coil then becomes an **electromagnet**. Because the size and direction of the current are changing all the time, the magnetic field being generated changes too.
- As a result, the soft iron core becomes magnetised. That magnetisation changes along with the magnetic field of the primary coil, the direction of the magnetic field flips round a hundred times per second, just like the alternating voltage through the primary coil.
- The result is that a changing magnetic field is also created in the secondary coil. That magnetic field in turn generates a (lower) alternating voltage between the ends of the secondary coil. This is the voltage that the appliance works on.



▶ **figure 7**
a transformer for use in the home (schematic drawing)

The electrical energy absorbed by the primary coil is given off by the secondary coil. During this process, no current runs from the primary to the secondary coil. The energy is transported by the magnetic field; electrical currents are not involved. We therefore say that the coils are **magnetically coupled** to each other.

Stepping voltages up and down

The voltage that the primary coil is connected to is called the **primary voltage**, U_p. The voltage delivered by the secondary coil is called the **secondary voltage**, U_s. When a transformer is stepping the voltage up, U_s is greater than U_p. When transforming down, U_s is smaller than U_p.

Whether the voltage will be higher or lower depends on the number of windings in the two coils. The following rule applies for the ratio of U_p to U_s:

$$\frac{U_p}{U_s} = \frac{N_p}{N_s}$$

where N_p is the number of windings in the primary coil and N_s is the number of windings in the secondary coil.

Worked example 1
The transformer for a doorbell converts an alternating voltage of 230 V AC into an alternating voltage of 12 V AC. The primary coil has 400 turns.
Calculate the number of windings of the secondary coil.

data — primary coil: $U_p = 230$ V, $N_p = 400$; secondary coil: $U_s = 12$ V

required — $N_s = ?$

working

$$\frac{U_p}{U_s} = \frac{N_p}{N_s} \rightarrow \frac{230}{12} = \frac{400}{N_s}$$

$230 \times N_s = 400 \times 12 = 4800$
$N_s = 4800 \div 230 \approx 21$ windings

Plus The ideal transformer

A transformer is an energy converter: it converts electrical energy at a high voltage into electrical energy at a low voltage, or the other way round. Very little energy is lost during this process. You can often assume in calculations that there is no energy loss at all. The error caused by this can often be neglected in practice.
The power drawn by the primary coil of an **ideal transformer** (i.e. one with zero energy loss) is the same as the power supplied by the secondary coil. Expressed as a formula:

$$P_p = P_s \quad \text{or} \quad U_p \cdot I_p = U_s \cdot I_s$$

▼ figure 8
a welding machine

Worked example 2

A welding machine (figure 8) is connected to the mains (230 V). During welding, the current through the primary coil is 16 A. The secondary coil delivers a voltage of 48 V.
Calculate the current in the secondary coil. Assume that the transformer in the welding machine is ideal.

data	primary coil:	secondary coil:
	U_p = 230 V	U_s = 48 V
	I_p = 16 A	
required	I_s = ?	
working	$U_p \cdot I_p = U_s \cdot I_s$	
	$230 \times 16 = 48 \times I_s$	
	$3680 = 48 \times I_s$	
	$I_s = 3680 \div 48 \approx 77$ A	

Exercises

1 Answer the questions below.
- **a** When do cooling towers have to be built near power stations?
- **b** Why is electrical energy transported at the highest voltage possible?
- **c** What is meant by an 'alternating voltage with a frequency of 50 Hz'? Explain.
- **d** What determines whether a transformer steps the voltage up or down?

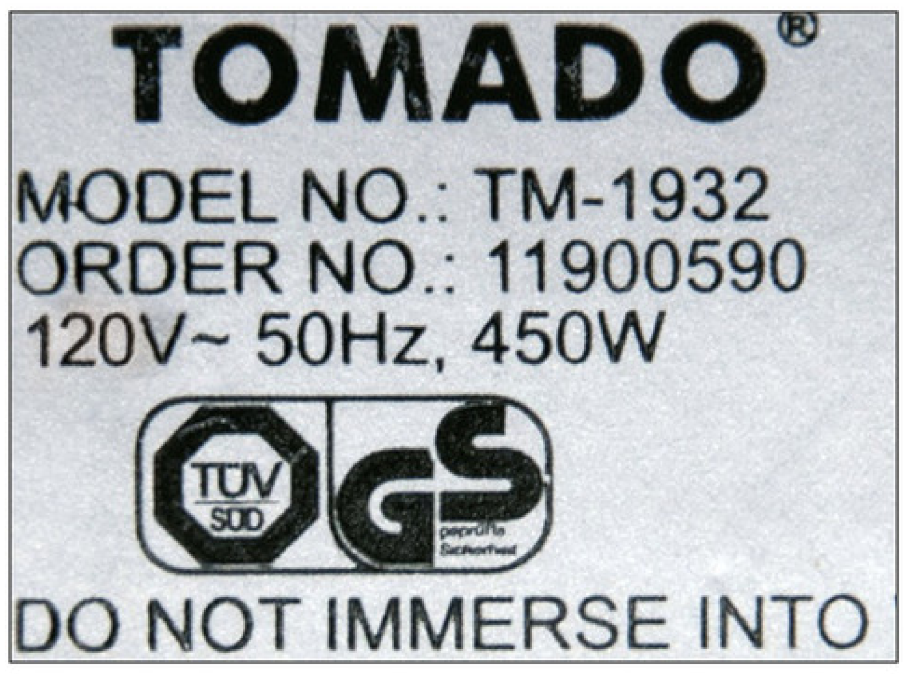
2 Look at the picture of the power station in figure 2.
- **a** What is the heat that is produced by the burners used for?
- **b** What makes the shaft of the turbine rotate?
- **c** Which device uses this movement to generate electricity?
- **d** Where is the voltage that this creates finally converted into a high voltage?

3 A transformer consists of two coils and a metal core.
- **a** What metal is the core made of?
- **b** Why is this metal chosen?

4 Frances is charging her mobile phone using an adapter. The voltage between the power station and her mobile phone has been transformed up and down several times.
Copy table 1 and complete it. For the voltages, choose between:
12 V – 230 V – 10 kV – 380 kV.

▼ **table 1** stepping the voltage up and down four times

the transformer	steps the voltage		
	up/down	from	to
at the power station		20 kV	
at the transformer station outside the city or village			
at the substation in the city or village			
in the adapter of her mobile phone			



▲ **figure 9**
the type plate of Suzie's coffee machine

5 Suzie has moved from America to the Netherlands. She wants to connect her coffee machine from the USA to the Dutch mains (figure 9). That is why she bought a "a voltage converter which converts the European voltage – a whopping 230 V – to the standard USA mains voltage".
The transformer in the converter has a secondary coil with 500 windings.
Calculate the number of windings of the secondary coil.

6 A doorbell says: 8.0 V/0.60 A. The bell is connected to the mains (230 V) using a transformer.
Calculate the ratio between the numbers of windings in the primary and secondary coils.

7 Nettie has three coils: coil A with 100 windings, coil B with 200 windings and coil C with 400 windings. She can make a simple transformer by placing two of the coils on a soft iron core.
Nettie has a source supplying 6 V AC.
Which combination of coils lets her:
a step the voltage up to 12 V (two possibilities)?
b step the voltage up to 24 V?
c step the voltage down to 3 V (two possibilities)?
d step the voltage down to 1.5 V?

8 Barry has a voltage source that only provides 6.0 V AC. He needs a higher voltage for the experiment that he wants to carry out. He therefore decides to make a transformer by himself. For this he can choose between four coils, with 200, 300, 400 and 600 turns respectively.
a Which combination of coils gives Barry the greatest increase in voltage?
b Calculate how high the secondary voltage will be if he uses this combination.
c The voltage source has a switch which can be set to two positions: = (V DC) and ~ (V AC).
Explain which type of current Barry has to set the switch to.

9 The maximum value of the alternating voltage in the mains is 325 V and the effective value is 230 V. The following applies for the conversion: $U_{eff} = x \cdot U_{max}$.

a Calculate *x*.

b A bulb delivers 6.0 W when it is lit by 12 V DC. You want the bulb to run on an alternating voltage.
What should U_{eff} be?

c Calculate U_{max} for the alternating voltage.

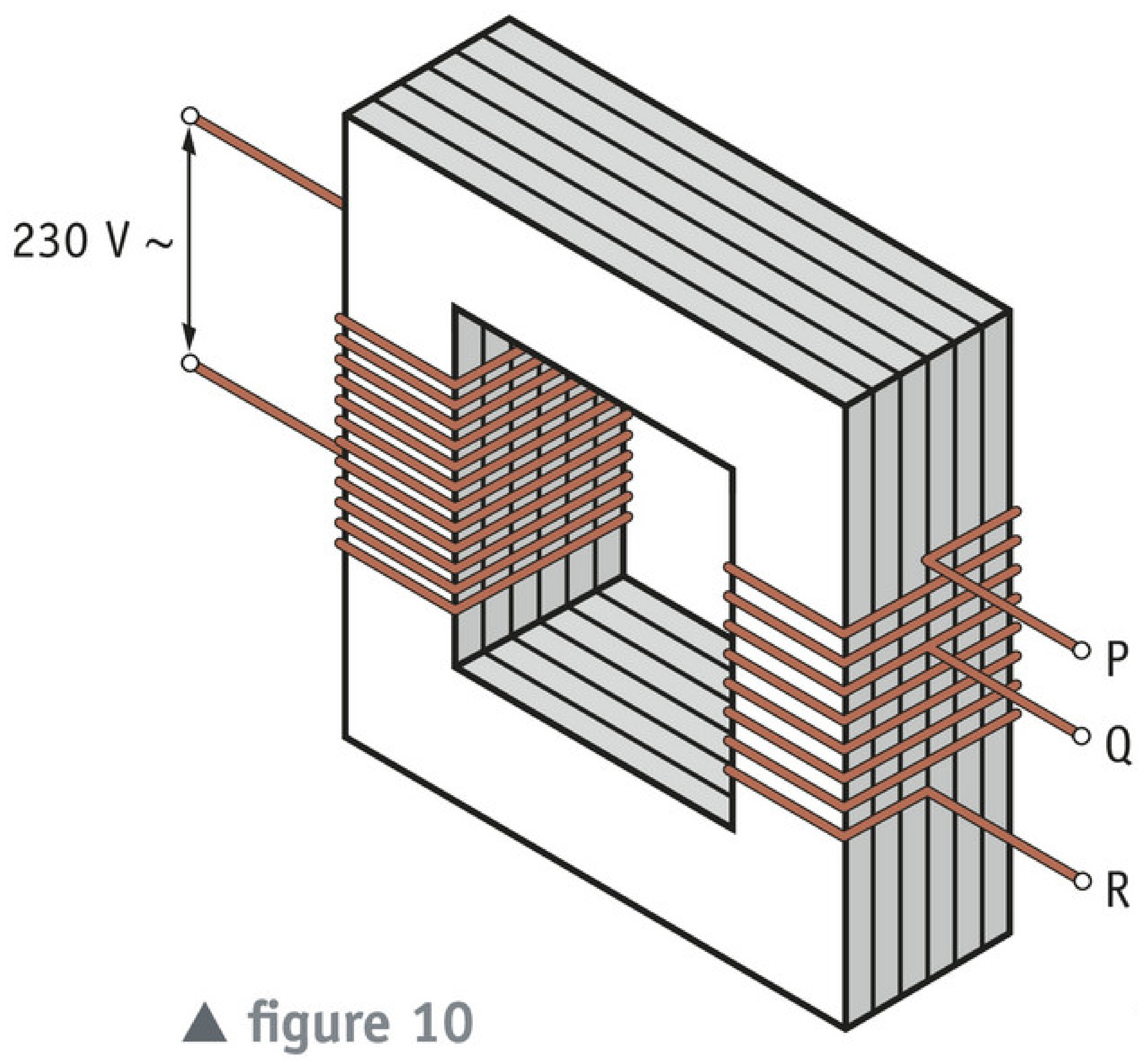
Plus The ideal transformer

***10** An electric doorbell works on the low voltage from a bell transformer. Figure 10 shows a schematic drawing of such a doorbell transformer. The primary coil is connected to the mains (230 V). There are three connection points on the secondary side: 3 V, 5 V and 8 V.

a How high will the voltage be between the connection points P and Q: 3 V, 5 V or 8 V? Explain your answer.

b The primary coil has 800 windings.
Calculate the (total number of) windings of the secondary coil.

c A doorbell is connected to connection points Q and R. If someone rings the doorbell, a current of 1.6 A will pass through the secondary circuit.
Calculate the current through the primary coil. Assume that it is an ideal transformer.



▲ **figure 10**
a doorbell transformer

11 Calculations often assume that a transformer is ideal. Leo wants to investigate how much a real transformer differs from this ideal. He uses the setup in figure 11 for this. Leo writes down the following data in one of his experiments:

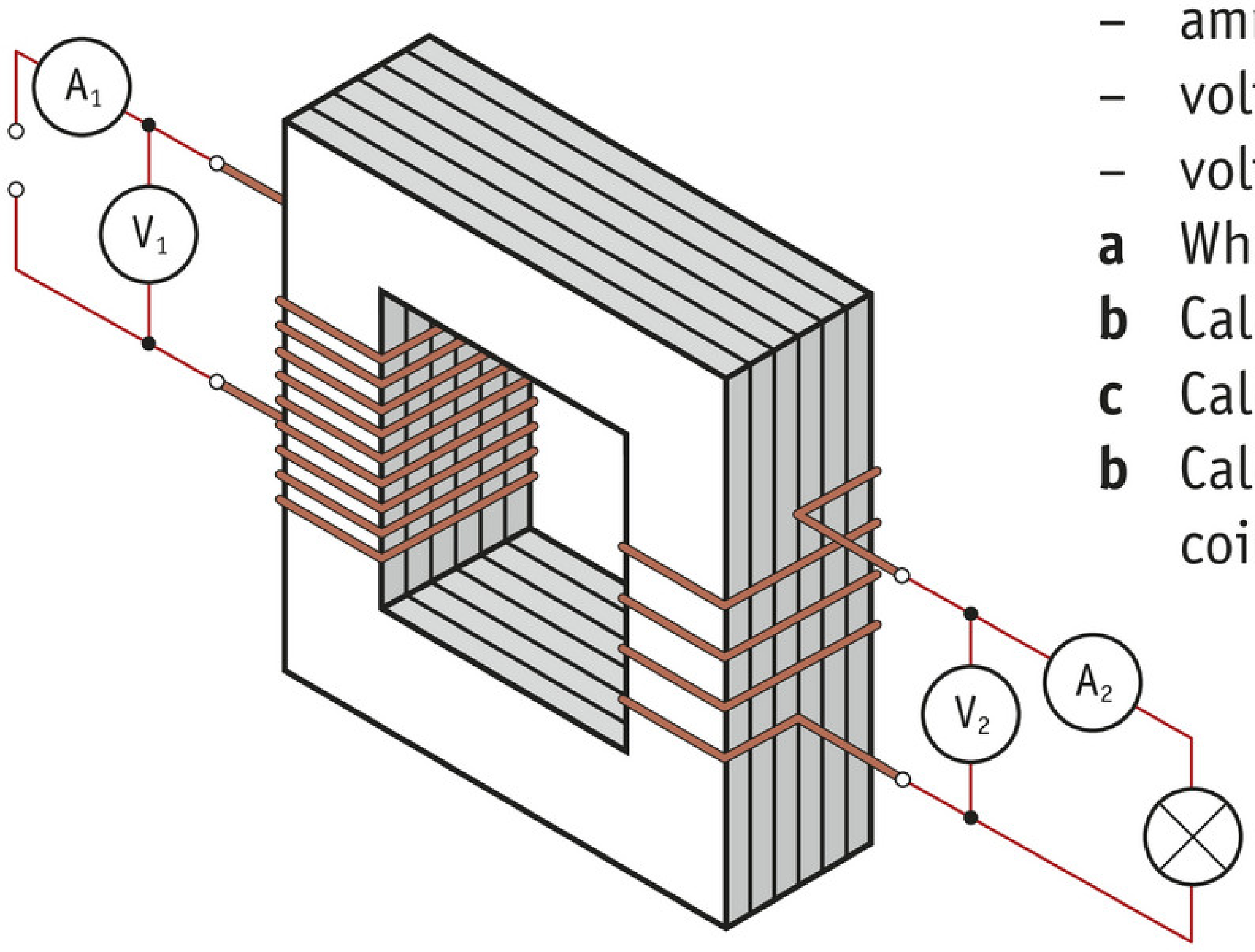
- ammeter 1: 0.25 A
- ammeter 2: 0.42 A
- voltmeter 1: 12.0 V
- voltmeter 2: 6.0 V

a What is an ideal transformer?

b Calculate the power consumption of the primary coil.

c Calculate the power delivered by the secondary coil.

b Calculate the percentage of the electrical power drawn by the primary coil that has been lost.



▲ **figure 11**
a schematic drawing of Leo's experimental setup

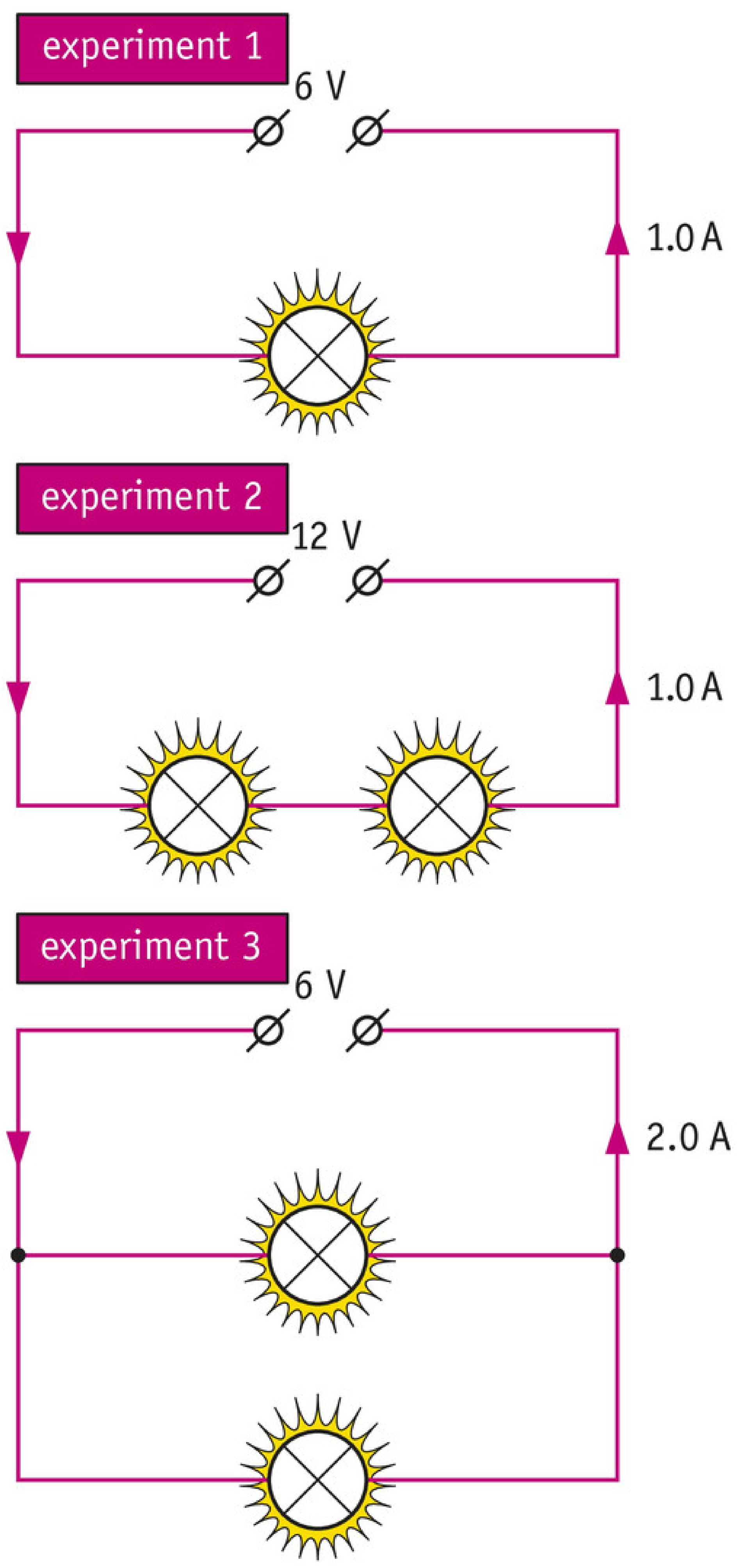
2 Power and energy

Televisions do not all convert electrical energy efficiently. One television may consume an amount of energy in two hours that another consumes in three hours. It may therefore be advantageous to buy a new, energy-efficient television. It can be worth it because the annual energy bill will be dozens of euros less.

Electrical power

Every electrical appliance states how much electrical energy it consumes per second. This is called the **power** of the appliance. The unit of power is the watt (W). If an appliance has a variable power, like a food mixer that has various positions, the maximum value is indicated (figure 12).

▲ **figure 12**
a food mixer with a maximum power of 175 W



▲ **figure 13**
The power depends on both the voltage and the current.

The power of a device depends on two factors: the voltage (across the device) and the current (through the device). You can check this by performing experiments as in figure 13.

- In experiment 1, one bulb runs on a voltage of 6.0 V. The current through the bulb is 1.0 A.
- In experiment 2, two identical bulbs are connected in series. To make sure that each of the two bulbs burns as brightly as the bulb in experiment 1, the voltage has to be raised to 12 V. Then there is 6.0 V across each bulb. This shows that when the voltage is doubled, the power is doubled too.
- Two identical bulbs are connected in parallel in experiment 3. The voltage source has been set to 6.0 V again. The current through each bulb is 1.0 A, making each of them burn as brightly as the bulb in experiment 1. You see when the total current is doubled to 2.0 A, the power is doubled too.

Stop 'silent' energy consumption

A lot of appliances consume energy when they are not being used if the plug is still in the socket. We call this wasted energy 'standby' or 'silent' consumption.

The top five appliances with the most silent consumption are:

1. **computer plus peripherals: € 33 a year**
2. **TV plus video or DVD player: € 15 a year**
3. **coffee percolator: € 6 a year**
4. **tuner, amplifier and CD player: € 6 a year**
5. **microwave oven: € 4 a year**

Standby wastage can easily be avoided using 'standby killers'.

Source: www.nuon.nl

▲ **figure 14**
Some appliances run at low power but are left on night and day.

This type of experiment shows that power depends directly on both voltage and current. You can therefore calculate the electrical power using the following formula:

$$P = U \cdot I$$

If you use a voltage U in volts (V) and the current I in amps (A), this gives you the power P in watts (W).

Calculating the energy consumption

A device may require a lot of power, but if you do not use it much, its energy consumption will not be high. Conversely, a device that uses very little power may have an unexpectedly high energy consumption if it is left on night and day (figure 14). The energy consumption of an appliance is therefore determined not only by its power but also by the period of time for which it is consuming energy.

You can calculate the energy consumption by multiplying the power by the period of time. Expressed as a formula:

$$E = P \cdot t$$

If you use the power P in watts (W) and the time t in seconds (s), this gives you the energy consumption E in joules (J).

Worked example 3
John uses a 175 W mixer to whip cream. The whipped cream is ready after whipping for 3.0 minutes and he then switches off the appliance. Calculate the energy consumption of the mixer (in kilojoules (kJ)).

data	$P = 175$ W $t = 3.0$ min = 180 s
required	$E = ?$
working	$E = P \cdot t = 175 \times 180 = 31{,}500$ J ≈ 32 kJ

The joule as the unit of energy

You cannot do much with one joule of electrical energy. You could use that amount of energy to:

- light a 1 W bulb for one second;
- lift an object weighing 100 grams by about 1 metre;
- raise the temperature of 1 gram of water by 0.24 °C.

The amounts of electrical energy consumed by electrical appliances are much higher. These amounts are therefore often measured in kilojoules (kJ) and megajoules (MJ). These are more useful sizes for measuring these amounts. For instance, the battery of a smartphone contains 15 to 25 kJ of electrical energy when it is fully charged, and a family of four consumes 45 MJ of electrical energy on average a day.

▲ **figure 15**
the energy in peanut butter

Joules are not only used for electrical energy, but also for other types of energy. For instance, the energy value of foodstuffs is often expressed in kilojoules per 100 grams. The label in figure 15 shows that 100 g of peanut butter provides 2700 kJ of energy. If you put 15 g of peanut butter on a sandwich, its energy value is therefore: 15 × 27 = 405 kJ.

Measuring energy in kWh Experiments 2 and 3

Although the joule is the official unit of energy, another unit is used on the electricity bill: the kilowatt-hour (kWh). The same unit is stated on the meter that measures the consumption of electrical energy in your home (figure 16). This is why this type of meter is known as a **kWh-meter**. In the formula $E = P \cdot t$, you can give the power P in kW and the time t in hours; this then gives you the energy consumption E in kilowatt-hours.

The kWh is an old-fashioned unit that is actually not really needed. In principle, energy consumption could be measured in MJ just as well. But the energy companies are still sticking to kWh, because all their systems are set to use that unit. In addition, they would have to replace six or seven million kWh-meters with MJ-meters in the Netherlands alone, and that would be much too expensive.

As both units are used at the moment, you sometimes have to convert a quantity of energy from kWh into J or the other way round. What you have to remember is that 1 kWh is the same as 3.6 MJ. Work it out for yourself: if a device with a power of 1 kW (= 1000 W) runs for exactly 1 hour (= 3600 s), it consumes:

$E = P \cdot t$	$E = P \cdot t$
$E = 1\ \text{kW} \times 1\ \text{h}$	$E = 1000\ \text{W} \times 3600\ \text{s}$
$E = 1\ \text{kWh}$	$E = 3.6 \cdot 10^6\ \text{J} = 3.6\ \text{MJ}$

◀ **figure 16**
A kWh-meter measures the consumption of electrical energy.

▲ **figure 17**
Marian's desk lamp

Worked example 4
Marian estimates that her desk lamp (13 W) is on for approximately 60 hours in a month (figure 17).
Calculate:
– how much electrical energy the lamp consumes in 60 hours.
– how much that electrical energy costs. (1 kWh costs € 0.22 at 2014 prices.)

data	P = 13 W = 0.013 kW t = 60 h
required	E = ?
working	$E = P \cdot t = 0.013 \times 60 \approx 0.78$ kWh price: 0.78 × € 0.22 ≈ € 0.17

Plus The power of a human

Your body does work by using the energy in your food. You will notice that if you start working out on an empty stomach you will soon run out of energy. Racing cyclists have to eat a lot to make sure their body has enough energy, not only before and after a race, but also when they are cycling (figure 18).

The amount of energy that your body consumes per second, is called the **power consumption**. If you cycle as fast as you can for an hour, the power used will be 200 to 400 W. Your body then needs 200 to 400 J of energy every second to maintain this effort. A professional racing cyclist may have an output of as much as 1600 W during a race.

▼ **figure 18**
Racing cyclists are given food and drink during the race too.

Your body can convert approximately 25% of the input energy into movement. The rest is converted into heat. That is why you get hot quickly when you are working out. The **actual power** is therefore only 25% of the power drawn. During lengthy exertions, your actual power will be between 50 and 100 W.
A kitchen mixer, which uses energy much more efficiently, will easily beat that.

Exercises

12 Answer the questions below.
- **a** Which two factors determine the power of an electrical appliance?
- **b** How is it possible that a device that does not require much power sometimes uses a surprisingly large amount of energy?
- **c** What formula can you use to calculate the energy consumption of an electrical appliance?
- **d** What instrument measures how much electrical energy is consumed in the home?

13 Table 2 shows a list of variables and units that are used in this section. Write down the missing words and symbols (letters) in the table.

▼ **table 2** variables and units

variable	symbol	unit	symbol
			A
	U		
power			
		joule	

14 Calculate the power of the appliances below.
- **a** Anthony's calculator works on a 1.5 V battery; its current is 0.08 mA.
- **b** Bridget's vacuum cleaner is connected to the mains (230 V); its current is 7.8 A.
- **c** Connie turns on the starter motor of her car; the battery delivers 8.1 V at a current of 160 A.

15 When a large power station is operating at peak power, it delivers 1200 MW of power to the electricity grid. An average household draws 800 W of electrical power on average during the hours that the electricity consumption is at its peak.
- **a** See 'Skills 2' at the back of the book.
  Calculate how many households can be supplied with electrical energy by the power station.

  If you need more practice, go to the V-trainer.

- **b** Most power stations operate way below their peak output capacity during most of the day.
  Explain why.

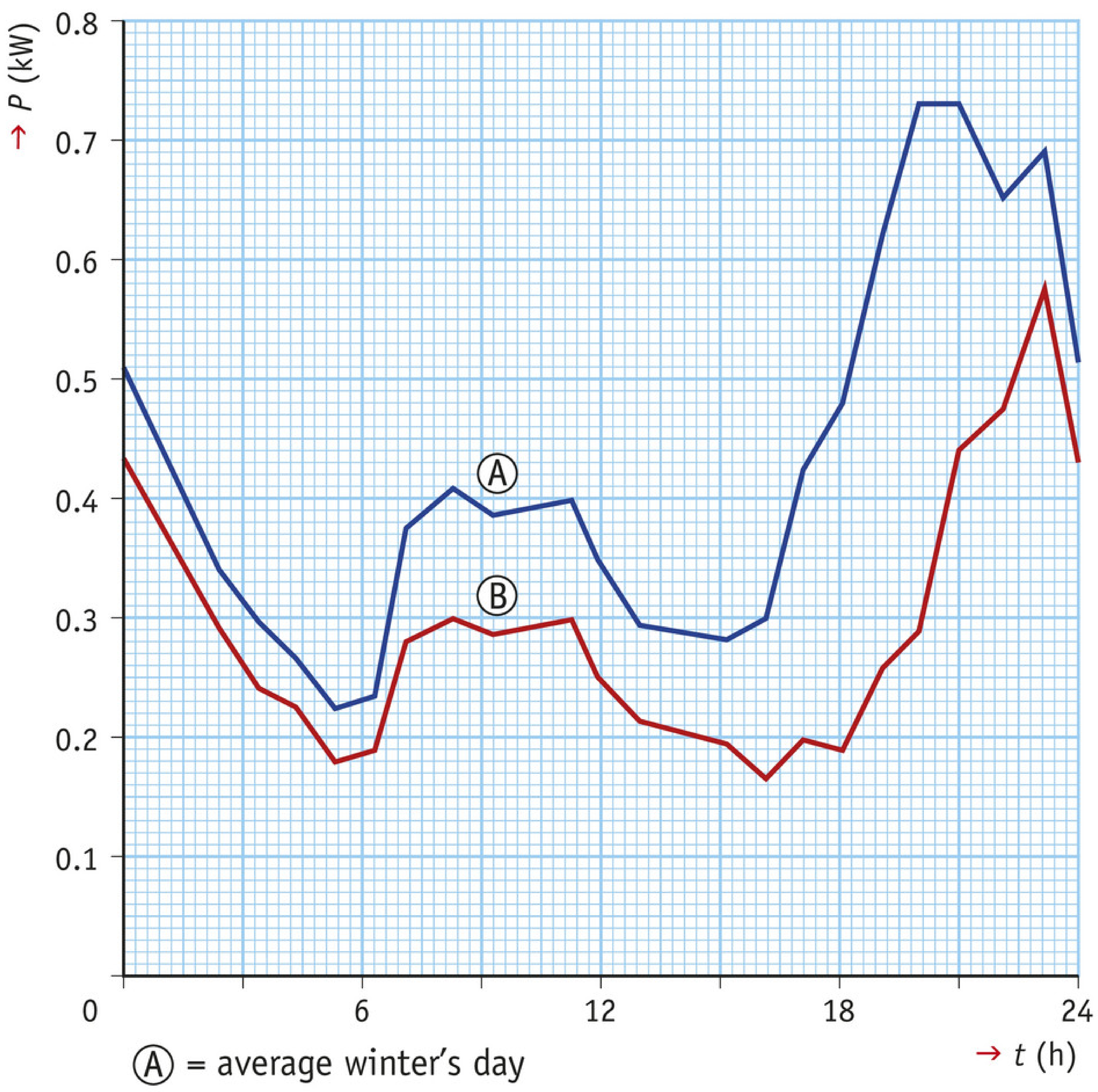
16 A lot of electrical appliances are left on in the home of an average family. The power of all these devices together is called the total connected power. You can see in the graph of figure 19 how this power changes in the course of the day.

a At which point in time is the most power supplied in winter? How much power is that?

b At which point in time is the most power supplied in summer? How much power is that?

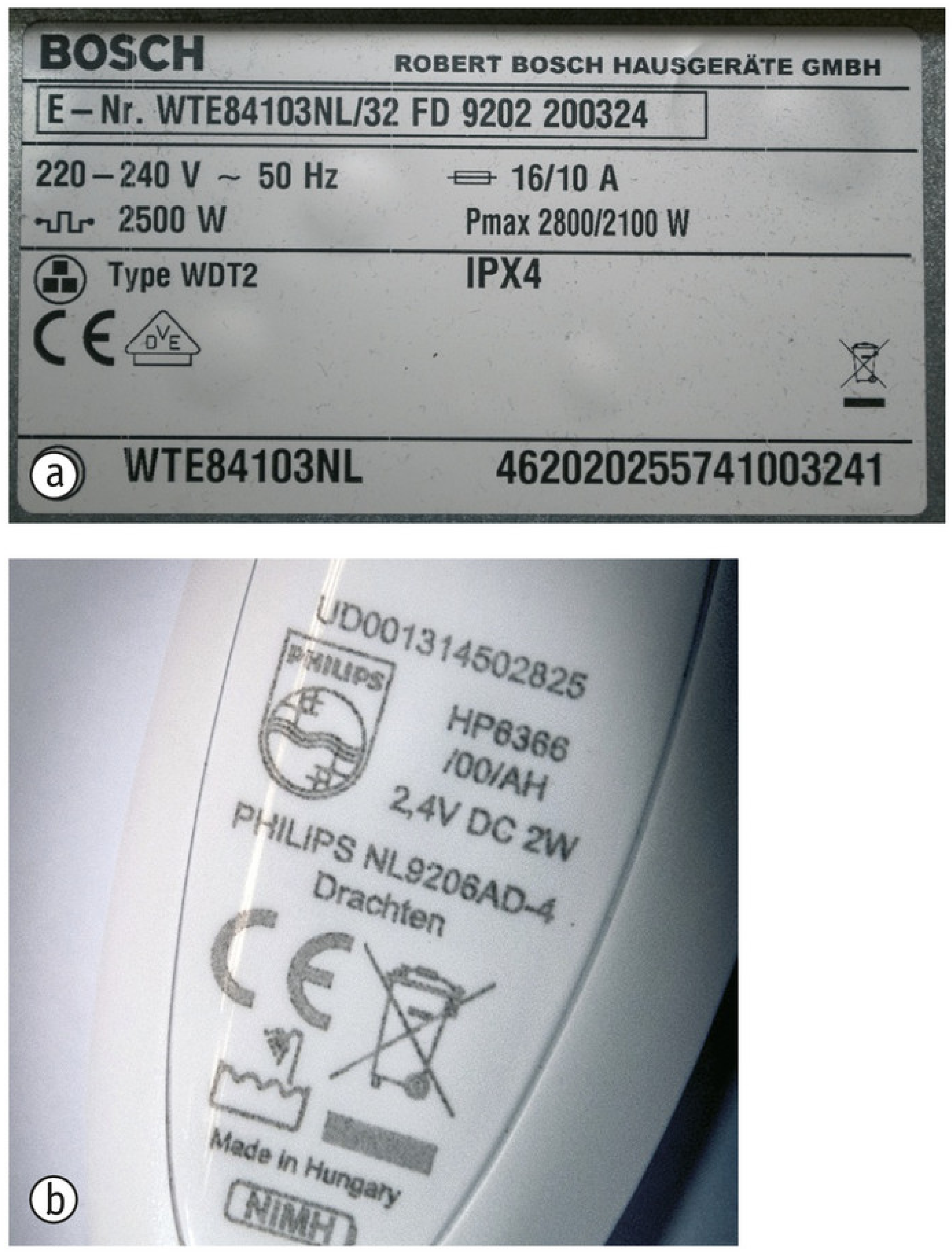
c Explain why less electrical energy is consumed after the switch to summer time.

▼ **figure 19**
The power drawn goes up and down considerably.



Ⓐ = average winter's day

Ⓑ = average summer's day



▲ **figure 20**
type plates of a tumble dryer (a) and a shaver (b)

17 Figure 20 shows the type plates of a tumble dryer and a shaver.

a See 'Skills 6' at the back of the book.
It takes 1.5 hours for the dryer to make sure that the clothes are dry enough to put in the drawers.
Calculate how much electrical energy is required for this (in joules and in kilowatt-hours).

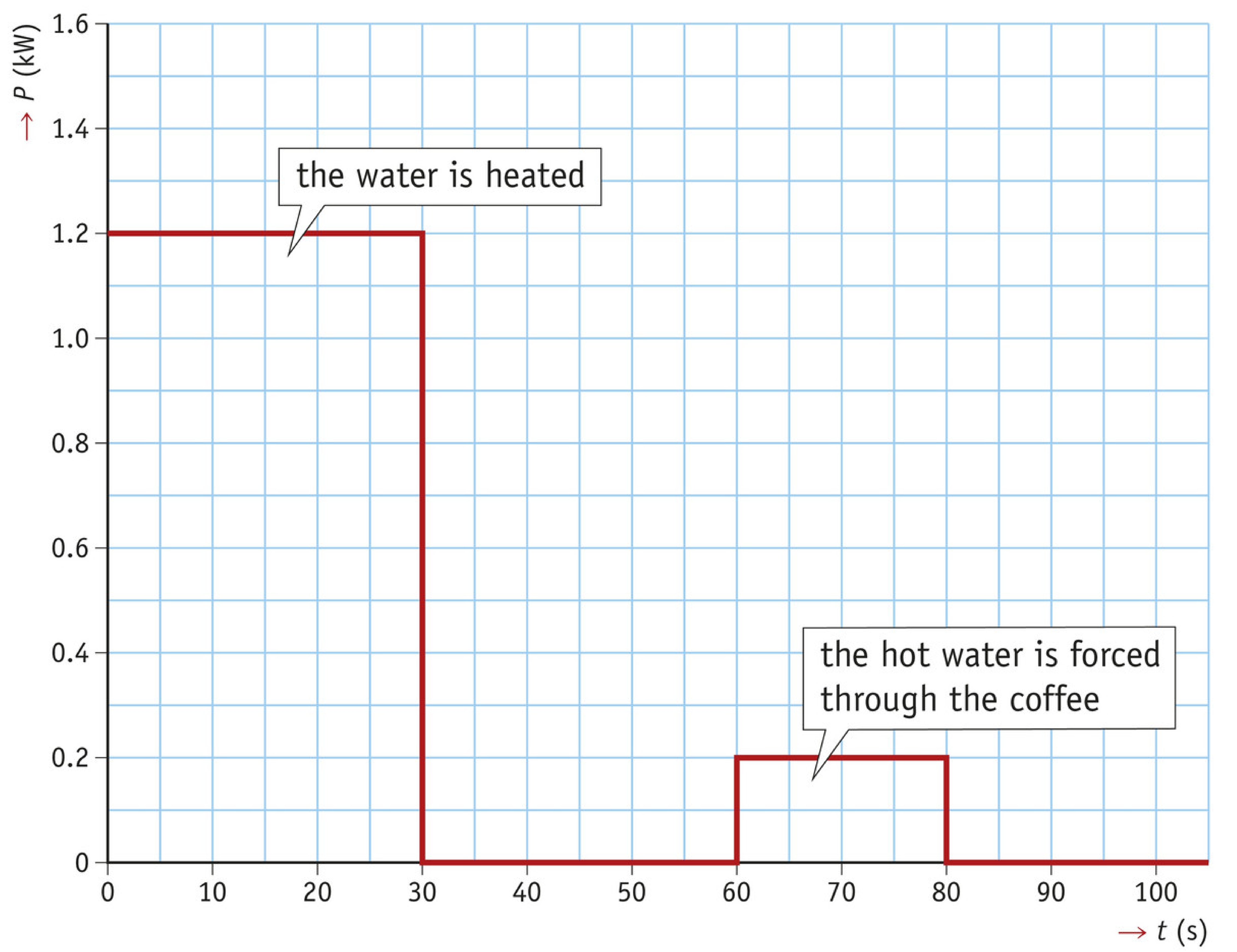
b Joey needs 6.0 minutes every morning for a good clean shave.
Calculate how much electrical energy is required for this (in joules and in kilowatt-hours).

If you need more practice, go to the V-trainer.

c If you buy an electrical appliance, it may be important to consider its power rating.
For which appliance do you have to keep it in mind: a tumble dryer or a shaver? Explain your answer.

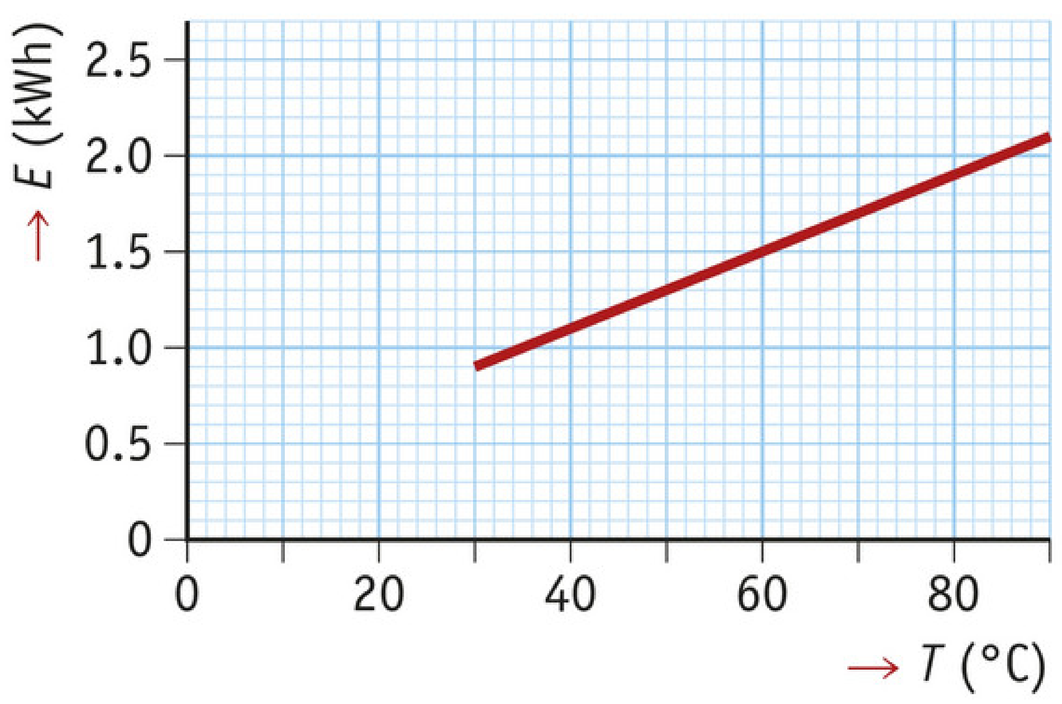
In the following exercises, assume that 1 kWh of electrical energy costs € 0.22.

18 A coffee pad machine is a quick way of making a cup of coffee. This machine heats the right amount of water first. After that it forces the hot water under high pressure through a coffee pad. Figure 21 shows you how the power goes up and down as it does that.
Using the data in the figure, calculate how much electrical energy is required to make a cup of coffee.



▶ **figure 21**
the (*P*,*t*) diagram of a coffee machine

***19** Desiree uses her washing machine twice a week. She does the wash at 60 °C. She wants to save on her energy costs and wonders how much she will save if she did her laundry at 30 °C from now on. In figure 22, the energy consumption of the wash cycle has been plotted against the temperature of the washing water.
Calculate how much money Desiree can save annually.



T = temperature of the washing water
E = energy consumption of the wash cycle

▲ **figure 22**
the energy consumption of the wash cycle

***20** When Jacqueline is not watching TV she always leaves it on standby. She wonders if this means her energy bill is much higher. To find out, she measures the power consumed by her TV when it is on standby. That turns out to be 4.0 W. When the TV is on, the power is 260 W.

a Imagine that the TV is left on standby for a whole year.
Calculate how much electrical energy the TV uses on an annual basis.

b Calculate how much she will be charged for this electrical energy.

c Jacqueline watches TV for 1.5 hours a day on average.
Calculate how much electrical energy the TV uses in total.

d What percentage of this total is caused by the ‘silent’ energy consumption?

Plus The power of a human

***21** The chargers of mobile phones used to work with a transformer. Those chargers were heavy and became hot during charging. Modern chargers use an electronic circuit to transform the voltage of the mains. An old-fashioned charger is connected to the mains and to a mobile phone (5.0 V). The charger then consumes 9.2 W of mains power. 25% of the energy consumed is lost in the transformer.
Calculate the current from the charger to the phone.
Source: IJSO

22 Read the text in figure 23 about the energy requirements of young people.

a What formula can you use to calculate the power drawn if you know the energy consumption and the time?

b Calculate the average power for:
- a 14-year-old boy.
- a 14-year-old girl.

c Compare the values that you have calculated in b against the values for the power that are stated in the text. Explain the differences.

The average energy requirement of a 14-year-old girl is 9.6 million joules a day; the average energy requirement of a 14-year-old boy is 12.6 million joules a day. Your energy demand will be higher if you spend a lot of time doing sports.

▲ **figure 23**
an excerpt from a text book about healthy nutrition

***23** A kinesiologist uses a test setup with a home trainer to determine the actual power output of an athlete. During one of her measurements, the athlete cycles for half an hour at a steady high speed. The measurement shows that his effective power output during cycling was 350 W.

a Estimate the power the athlete used up during cycling.

b Calculate the estimated food energy consumption of the athlete using your answer to question a.

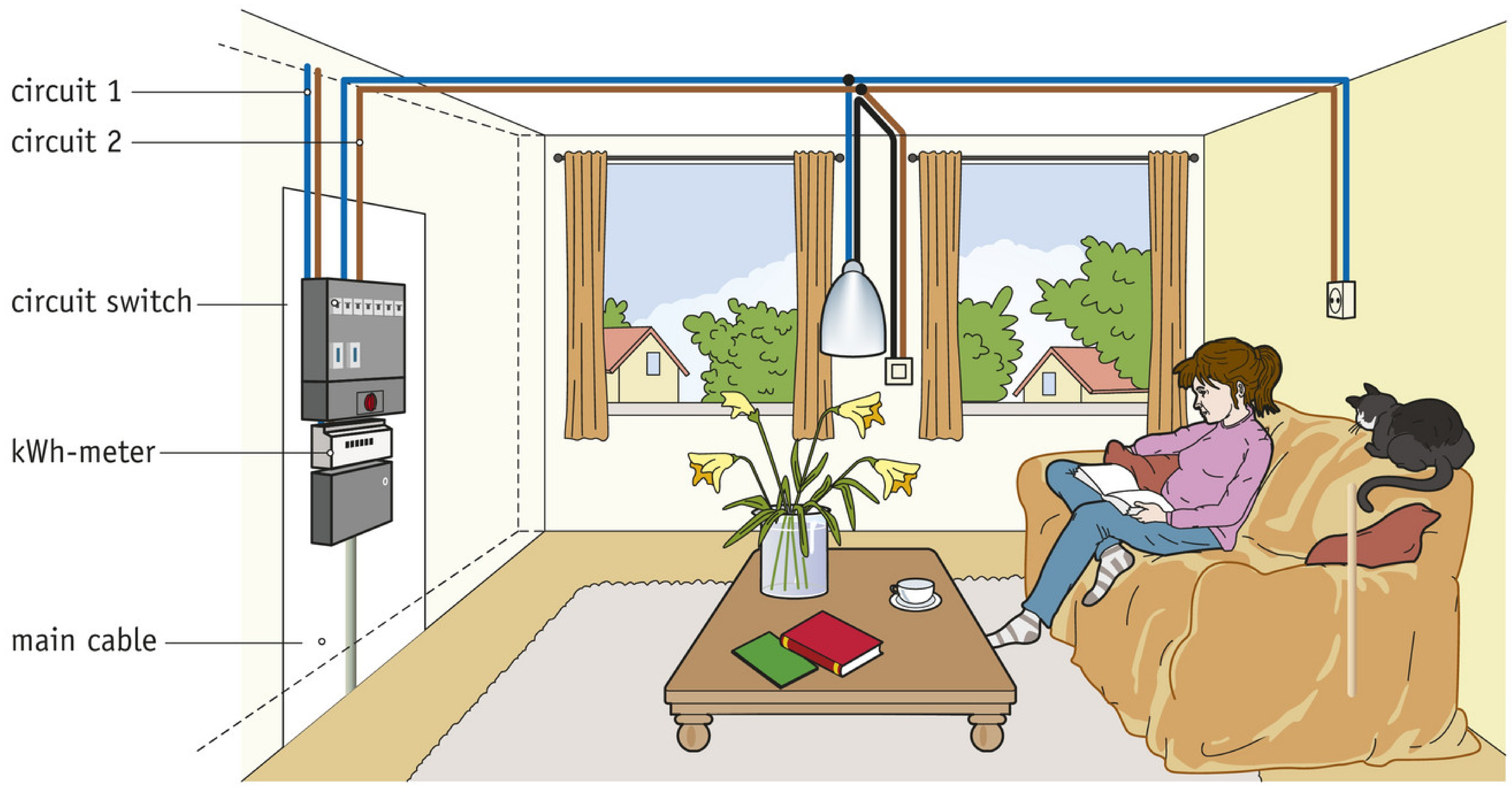
c The energy value of cooked pasta is approximately 480 kJ per 100 g. How much pasta does the athlete have to eat to supplement all the energy that his body has consumed during cycling?

3 Electricity in the home

The list of things that you need electrical energy for is a long one. DIY, cooking, gaming, searching for information, making coffee, listening to music, watching TV, doing the laundry: you cannot do anything without a continuous supply of electrical energy.

A domestic electrical system

A network of electricity wiring runs through the walls and ceilings of a home: the **domestic supply**. This lets you use electrical energy anywhere in the house. Figure 24 shows you how the electricity mains enters the house near the front door. After the kWh-meter, the line splits up into four to six parallel circuits. For the sake of clarity, just two such circuits have been drawn in figure 24.



▶ **figure 24**
part of the electrical system in a home

A circuit consists of various branches in parallel, each leading to one socket or one light fitting. This means that every single light fitting and socket has a voltage of 230 V. The voltage U is therefore the same everywhere in the circuit:

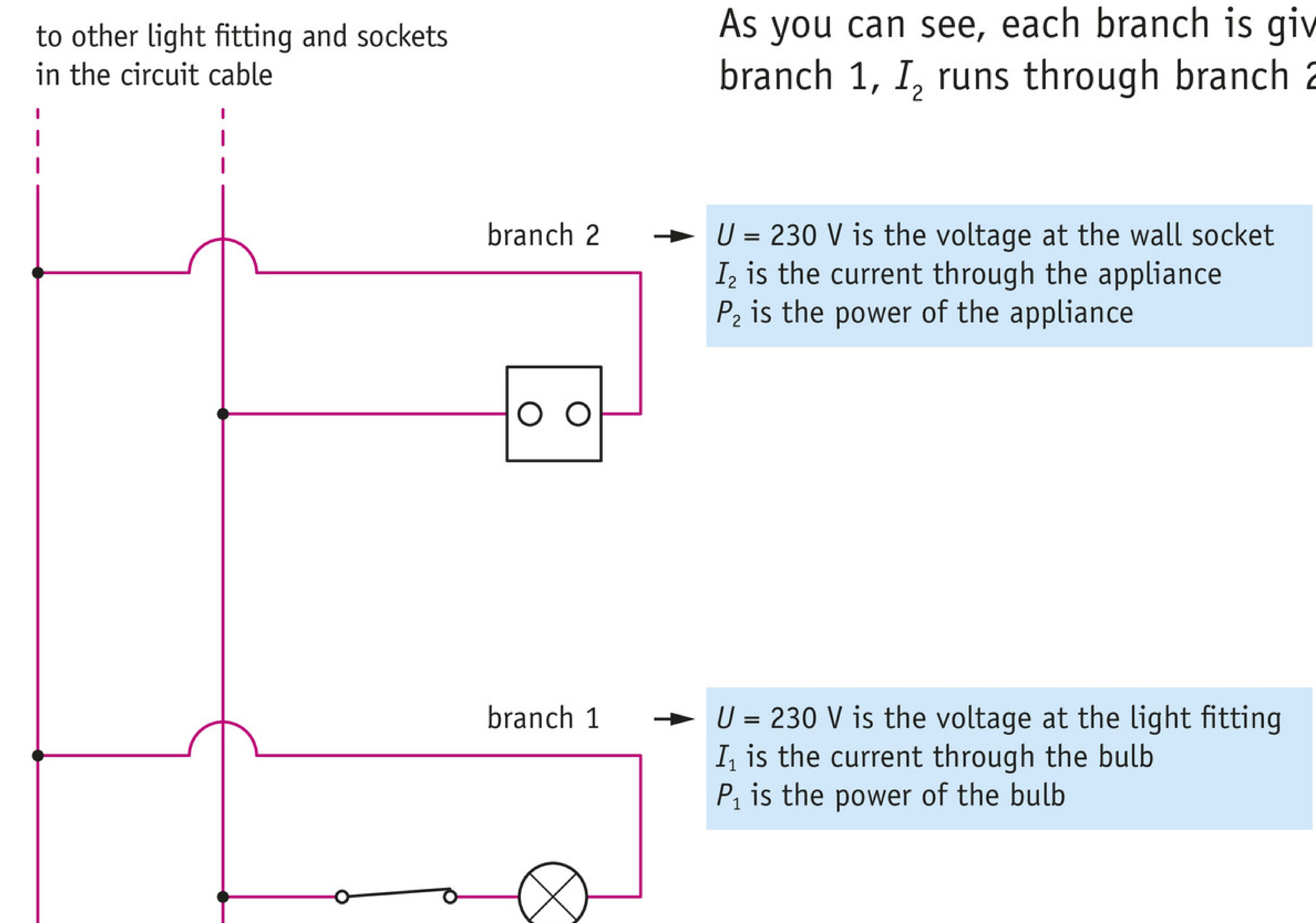
$$U = U_1 = U_2 = U_3 = \ldots = 230 \text{ V}$$

Each circuit has its own **circuit switch** that you can use to disconnect all its sockets and light fixtures from the power supply. This makes it safe for you to perform repairs or connect an additional socket.

If a device is on, current will run through the branch that it is connected to. The greater the power consumption of the appliance, the higher the current. If you add up all the currents in all the branches this gives you the total current I_{tot} in the circuit. Expressed as a formula:

$$I_{tot} = I_1 + I_2 + I_3 + \ldots$$

As you can see, each branch is given a number of its own. I_1 runs through branch 1, I_2 runs through branch 2, etc. (figure 25).



▲ **figure 25**
All light fittings and sockets in a circuit are connected in parallel.

The total power drawn

The appliances that are connected to a circuit are almost never all on at the same time. You can calculate the total power P_{tot} (of the appliances that are on) using the formula:

$$P_{tot} = P_1 + P_2 + P_3 + \ldots$$

If a 15 W appliance and a 40 W appliance are on at the same time, the total power being drawn is therefore 55 W. Which is logical when you remember that 1 W is the same as 1 J/s. If one appliance consumes 15 J/s, and the other 40 J/s, this gives you a total of 55 J/s or 55 W.

A second formula can be derived for P_{tot} with a few calculations:

$$\begin{aligned} P_{tot} &= P_1 + P_2 + P_3 + \ldots \\ &= U \cdot I_1 + U \cdot I_2 + U \cdot I_3 + \ldots \\ &= U \cdot (I_1 + I_2 + I_3 + \ldots) \\ &= U \cdot I_{tot} \end{aligned}$$

You can therefore also calculate the total power drawn by multiplying the mains voltage (230 V) by the total current:

$$P_{tot} = U \cdot I_{tot}$$

Worked example 5

The following appliances are connected to one circuit of a domestic supply:

- an 800 W microwave
- a 2000 W kettle
- a 150 W extractor hood
- six 3.0 W LEDs

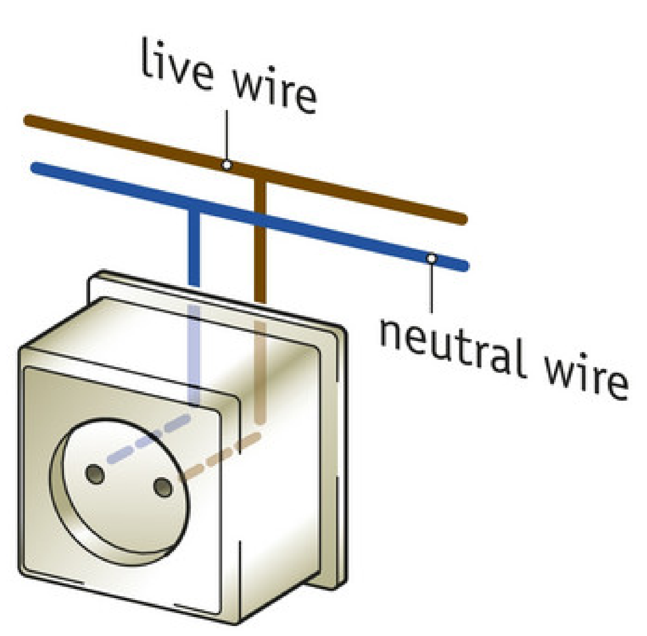
Calculate the total current in the circuit.

data
$P_1 = 800$ W
$P_2 = 2000$ W
$P_3 = 150$ W
$P_4 = 6 \times 3.0 = 18$ W
$U = 230$ V

required
$I_{tot} = ?$

working
$P_{tot} = P_1 + P_2 + P_3 + P_4$
$= 800 + 2000 + 150 + 18 = 2968$ W

$$I_{tot} = \frac{P_{tot}}{U} = \frac{2968}{230} \approx 13 \text{ A}$$



▲ **figure 26**
This is how a socket is connected.

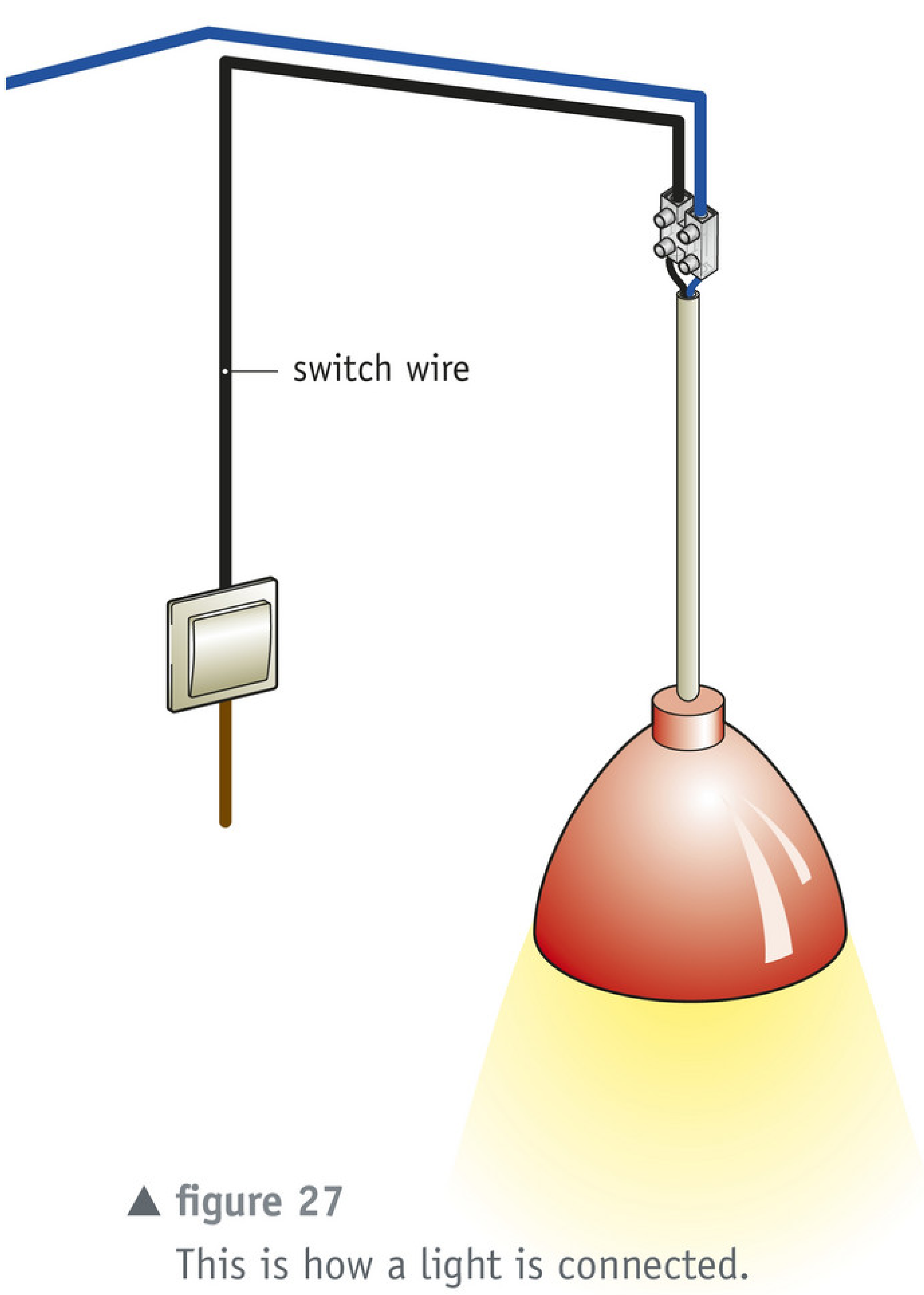
Live wire and neutral wire

Two wires go to each socket (figure 26). These wires have a copper core and a PVC insulation layer around them (PVC is a kind of plastic).
If everything has been connected properly, the brown wire is the **live wire** and the blue wire is the **neutral wire**.

The (brown) live wire has an alternating voltage of 230 V AC. You must not touch the copper core of this wire. If you do, a current will run through your body and you will get an electric shock. The (blue) neutral wire has no voltage. This wire is only there to complete the circuit that runs back to the power station.

If you touch the neutral wire, you should not feel anything. You do have to be careful with the blue wires too, though: someone might have switched the brown and the blue wire by accident. You should therefore disconnect the power supply first, before you touch any wire.

Figure 27 shows a drawing of how a ceiling light has been connected.
A black wire runs from a switch to a bulb: the **switch wire**. The connecting wire will only be live when the switch is in the 'ON' position.



▲ **figure 27**
This is how a light is connected.

Overload

The total current in any one circuit must not exceed 16 A. If the current is below this limit, electrical energy can be transported safely through the electrical wiring. However, if the current goes (well) above 16 A, the copper wire in the wiring will get hot, which creates a fire hazard.

One reason why the current may become too high is because too many appliances are switched on at the same time in a circuit. This is called **overloading**. To determine whether there is any risk of overloading, you should check the total power of the connected devices. As long as the total power does not exceed 3.7 kW, nothing will happen. Work it out:

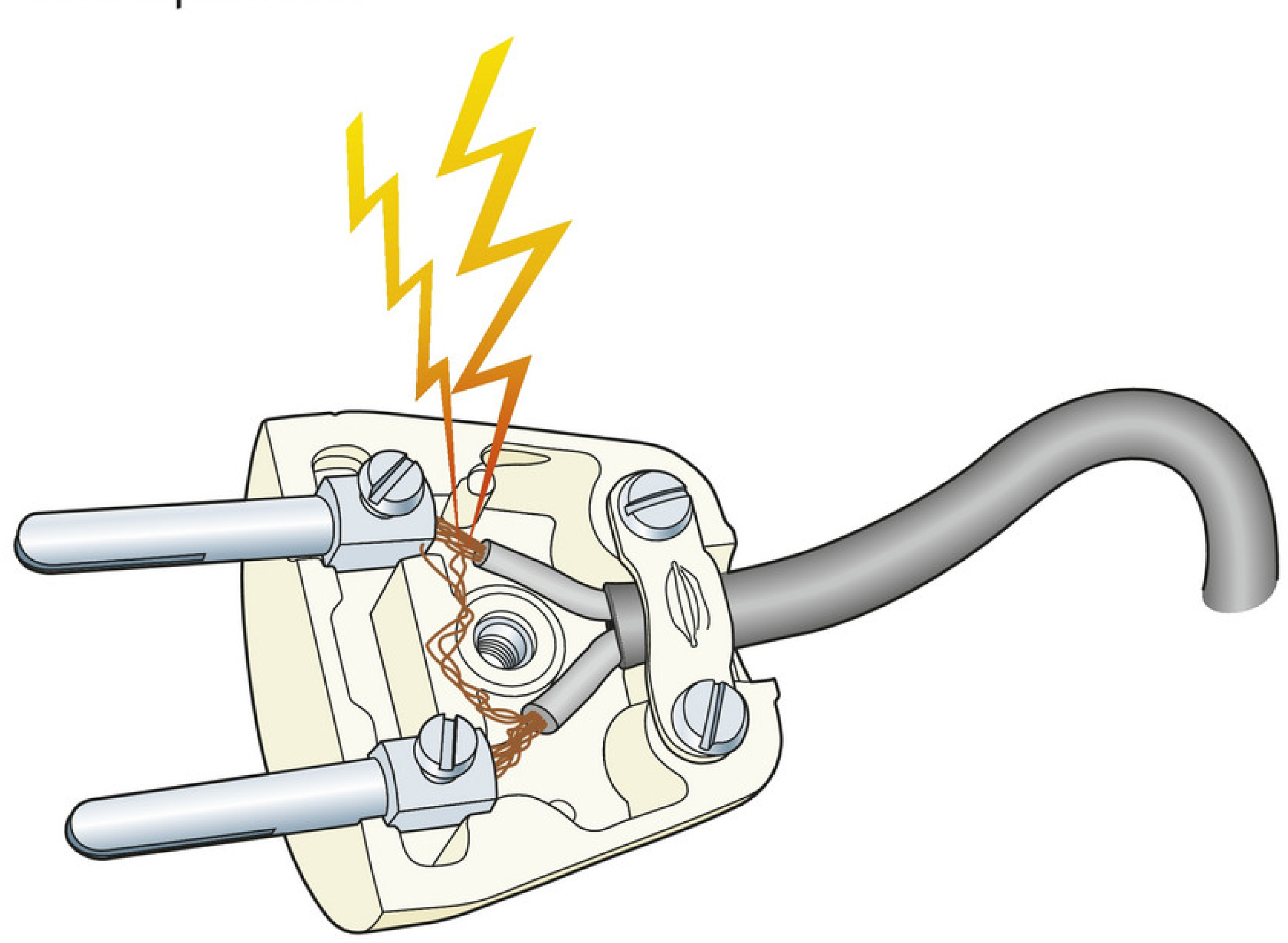
$$P_{max} = U \cdot I_{max} = 230 \times 16 = 3680 \text{ W} \approx 3.7 \text{ kW}$$

Short circuit

Electrical wires are made of thick, highly conductive copper wire. These wires only have very low electrical **resistance**. This means that current can pass through them easily. The same goes for the copper wire in the flex or cable to the appliance. The resistance of the appliance itself is much higher. In comparison, the resistance of the connecting wires is negligible.

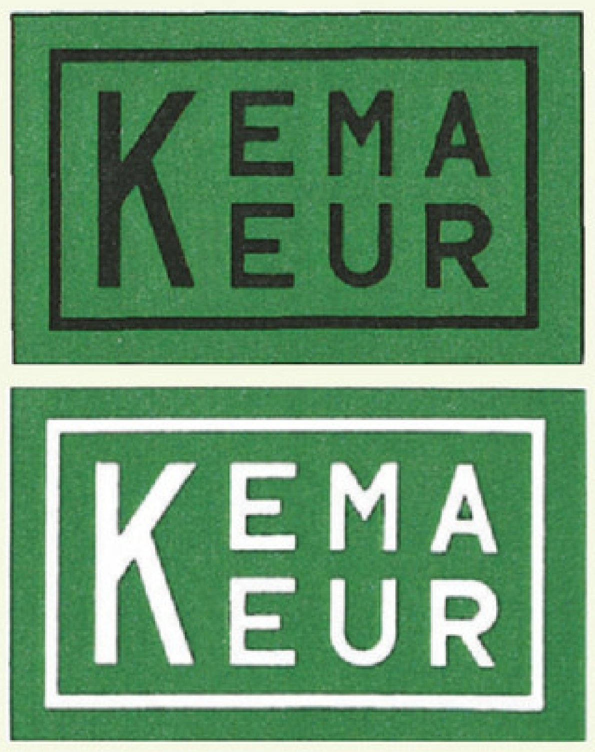
In practice, therefore, the resistance of the appliance determines the current. The current of a small device, such as an electric alarm clock, is approximately 0.01 A (10 mA). The current of a large appliance, such as a tumble dryer, may well be more than 10 A. However, the current can never exceed 16 A as long as the appliance is working as it should.

This may change if the current is able to take another path, with less resistance. This will then cause a **short circuit**. Figure 28 shows an example. The copper wires inside the plug are in contact with each other. This creates a circuit with far too little resistance. If you put that plug into the socket, the current would become enormous, with all sorts of consequences.



▶ **figure 28**
If you use this plug, it will cause a short circuit.

Plus KEMA

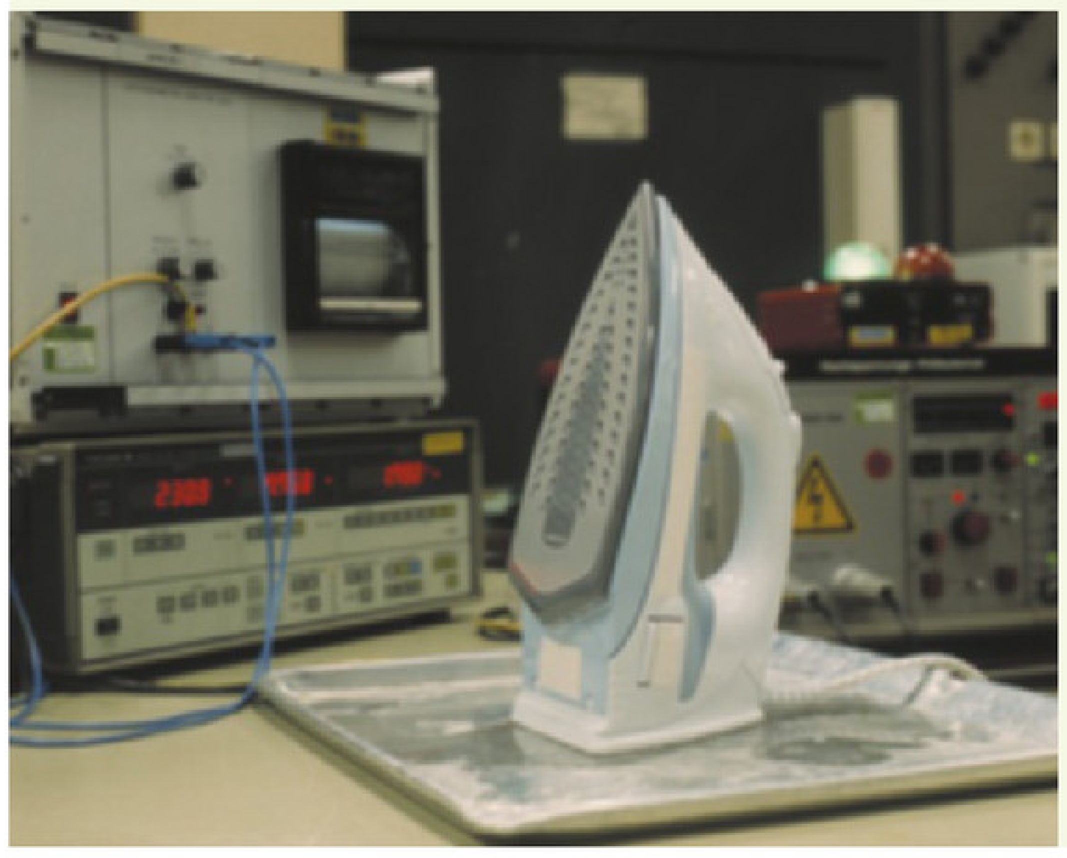


▶ **figure 29**
approved by KEMA

The company for the Inspection of Electrotechnical Materials (known in the Netherlands by its Dutch acronym KEMA) is known for the KEMA quality mark in particular. Figure 29 shows you what the KEMA quality mark looks like. It shows that KEMA has checked that an electrical appliance can be used safely.

A company cannot put a KEMA quality mark on a device just like that. The company has to test a number of prototypes or have them tested (figure 30). The KEMA quality mark can only be used once these prototypes have been proved to meet all the safety requirements.

To check that all the companies observe the rules properly, KEMA regularly performs random checks. A few appliances are then taken from a random shop and inspected to see if they are as safe as the prototypes. If such a random check shows that anything is wrong, the manufacturer will be warned immediately.

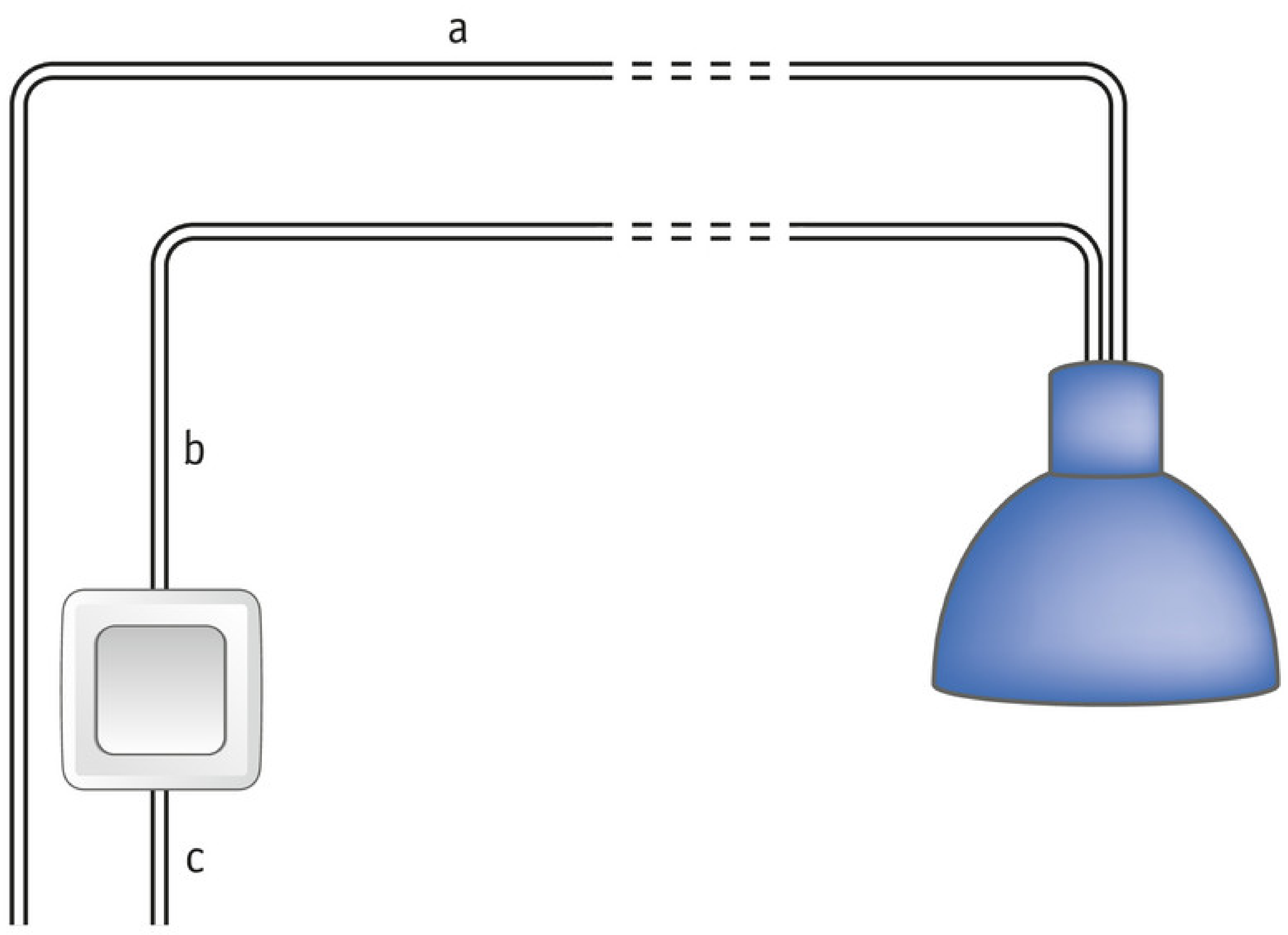


◀ **figure 30**
An iron being tested at KEMA.

Exercises

24 Answer the questions below.
- **a** Which two formulae can you use to calculate the total current in a circuit?
- **b** What are the differences between a live wire, a neutral wire and a switch wire?
- **c** What is the maximum (total) current in a circuit?
- **d** Which two situations can cause the current in a circuit to become too high?
- **e** What has happened when a short circuit occurs in a device? Explain.

25 Figure 31 shows you how a light is connected to the mains.
What letter is the label for:
- **a** the live wire?
- **b** the neutral wire?
- **c** the switch wire?



▶ **figure 31**
How has this ceiling light been connected?

26 Appliances such as washing machines, dishwashers and electric ovens are often given a circuit of their own. A new circuit is sometimes specially built in for them in older houses.

- **a** Explain why such appliances are given a circuit of their own. What would go wrong otherwise?
- **b** Why is a separate circuit like that not required for a toaster or a juicer?

27 You need worksheet 2-1 for this exercise.
A circuit in a domestic electricity supply has been drawn on the worksheet. As well as two lights that are connected to the circuit, you also see three switches: a, b and c.

- **a** Which of the three switches is the circuit switch? Explain how you can see that.
- **b** What is the function of the other two switches?
- **c** Give each wire the correct colour on the worksheet: brown, blue or black.

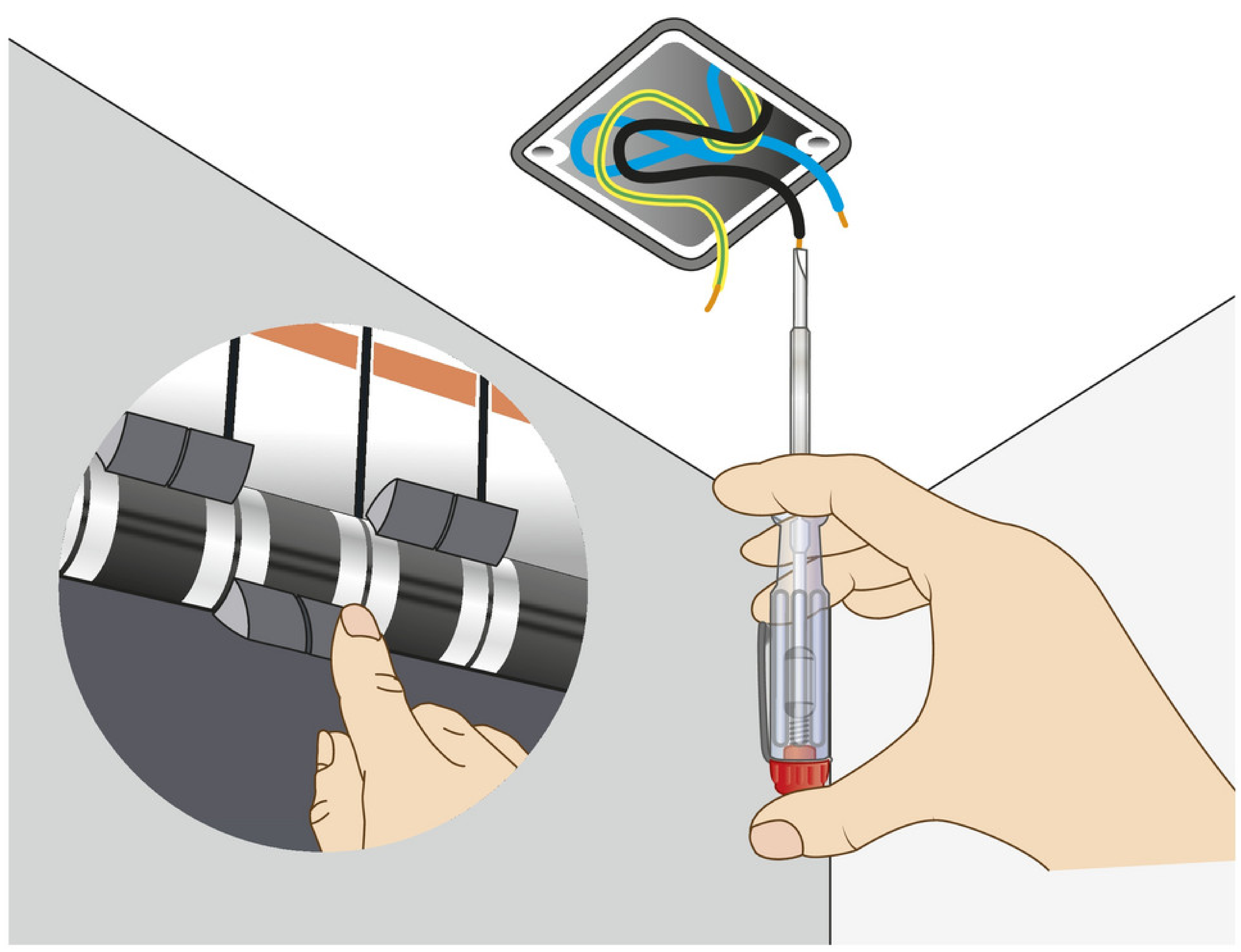
28 A pendant lamp is usually connected to a light fitting in the ceiling. A DIY book explains what you have to do when fitting it (figure 32).

- **a** The text mentions a black wire.
  What is the name of this wire?
- **b** What is the name of the other connecting wire? What colour is it?
- **c** You can make sure the black wire is 'dead' by turning the light switch off.
  Explain why this is not such a safe method.
- **d** What is a safer way to make sure that a light fitting or socket will be 'dead'?
- **e** Why is it sensible to lock the meter cabinet after that and to take the key with you?

▼ **figure 32**
an excerpt from a DIY book

Safety first

- **Before you start connecting the flex, make sure that the wires in the ceiling are not live. You can check this using a properly working voltage detector.**
- **If the black wire from the ceiling is still live, you can disconnect the voltage by switching off the appropriate light switch. However, it is always safer to switch off the circuit in question in the meter cabinet, lock the door of the meter cabinet and keep the key with you while you are working.**



29 The following appliances are connected to one circuit of a domestic electrical system:
- a 1600 W fryer
- one 12 W bulb and one 15 W bulb
- a 250 W extractor hood
- a 400 W TV

a Calculate the total current when all the appliances are on at the same time.
b Is the circuit overloaded if all appliances are on at the same time? Explain.

***30** A fan oven has a heating element that heats the air (1450 W), a fan to distribute the hot air (80 W) and a grill (1300 W).
Is it necessary to give this fan oven a circuit of its own, with no other appliances? Show this in a calculation.

230 V EXTENSION CABLE
- length 40 metres
- maximum power 1100 watt wound
- maximum power 3500 watt unwound

▲ **figure 33**
an advertisement for a cable reel

***31** A brochure contains an advertisement for a cable reel (figure 33). It warns that the cable can only transport a limited amount of power.
a Calculate the maximum current:
- when the cable is fully unwound.
- when the cable is still on the reel.

b Arnie uses the cable reel to connect a 2.8 kW electric heater to the mains.
Explain what could go wrong, if he does not unwind the cable fully first.
c How can you tell that the copper wire of the cable must be about the same thickness as the copper wire in the domestic electrical system?

32 You need worksheet 2-2 for this exercise.
Myrtle is using a voltage detector to check if a socket is live. You can see on the worksheet how she tests the left-hand hole of the socket. The neon bulb then lights up.
a Has the voltage detector contacted the live wire or the neutral wire? Explain.
b Will the neon bulb also light up if she inserts the voltage tester into the right-hand hole? Why?
c The voltage detector is partly made of insulating material.
Colour the parts that do not conduct the current blue.
d Explain why inserting a voltage detector into a socket hole is not dangerous. Use the word 'resistance' in your explanation.

Plus KEMA

33 A lot of electrical appliances in the Netherlands carry the KEMA quality mark.
- **a** What can a consumer tell from the KEMA quality mark?
- **b** Why does the KEMA perform random checks regularly?
- **c** What is meant exactly by a ‘random check’?

34 Read the newspaper report in figure 34.
- **a** What is wrong with some of the kettles that are sold in the Netherlands?
- **b** Are kettles with a CE label always safe? Explain.
- **c** A KEMA quality mark gives you ‘additional assurance’, says Harry van Doornum. Why does he think that?
- **d** What would KEMA pay attention to when inspecting kettles? Think up at least three things and write them down.

KEMA quality mark gives you additional assurance

Delft – A lot of electric kettles are unsafe. That was the conclusion of a study by the Dutch Commodity Inspection Department.

The department investigated 42 different kettles of 34 different brands. There were problems with ten of them in terms of safety, such as insufficient protection against spills. Users could run the risk of severe burns.

Kettles must have be CE approved. They are not allowed to be sold in Europe without this seal of approval. “However, they do not have to be inspected,” says expert Harry van Doornum of the NEN (Netherlands Standardisation Institute). “The manufacturers themselves can apply the approval mark as long as the kettle has been manufactured in accordance with European standards. Appliances with KEMA quality mark have been inspected, though. That gives the consumer additional assurance that the appliance is safe.”

▲ **figure 34**
Watch out for unsafe kettles!

4 Electricity and safety

Safety comes first when designing a domestic system. The wires are well-protected against damage and they are thoroughly insulated. They also have special safety features such as fuses and earth connections. The chance of an accident with electricity is therefore very small as long as you are careful.

▲ **figure 35**
If you touch electric fencing, your muscles will contract powerfully for a moment.

Dangers of electricity

Using electrical energy is associated with two hazards.

- If wires have to carry too much current, they can become so hot that they cause fires. This hazard can occur as a result of overloading or a short circuit.
- If you touch a live conducting object, you will get an electric shock. You might notice this if you touch the electric fencing around a meadow. A short electric shock runs through your body and it is not a pleasant sensation (figure 35).

If the current passing through your body is not too high (or only for a moment, as with electric fencing), you will manage to control your muscles. You can let go of the live object immediately. But if the current is higher and does not stop immediately, your muscles cannot relax. You cannot let go of the live object anymore. Table 3 shows you what the consequences can be.

▼ **table 3** the effect of current on your body

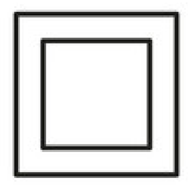
current	symptom
1 mA	You can hardly feel it.
10 mA	tingling sensation
15 mA	muscular contractions
15-100 mA	pain, unconsciousness, trouble breathing
100-500 mA	heart problems
more than 1 A	life-threatening, burns

The size of the current depends on the voltage and the resistance of your body. Your body conducts currents quite well: the **electrical resistance of your body** is therefore not very high. The highest resistance to the current is at the locations where it enters and leaves the body. This is called the **contact resistance**. If your skin is dry, contact resistance will be very high. But if your skin gets wet, this will greatly reduce the contact resistance.

Single and double insulation

The wires in the household electrical system have copper wire as their core. The thickness of this wire has been chosen so that currents up to 16 A can run through it easily, without significant heat production. An insulation layer of coloured PVC makes sure that you will not get a shock when you touch the wire. The insulation is also needed to prevent short circuits.

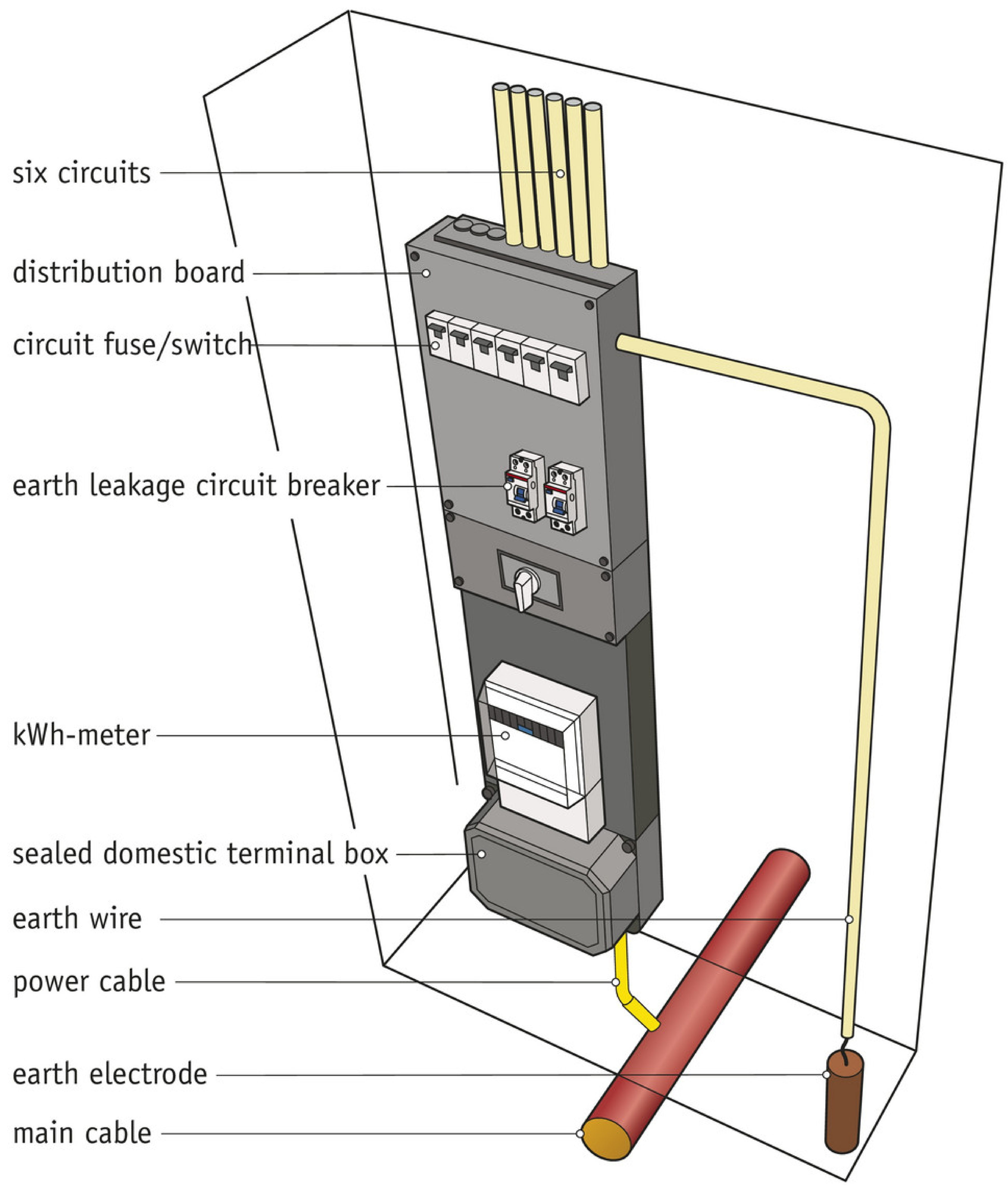
Some electrical appliances are double-insulated. The parts that the current runs through are insulated as normal. Additionally, there is a second insulating layer. The outside of the appliance is usually made of a non-conducting plastic. You can recognise an appliance that is **double-insulated** by the symbol shown in figure 36.



▲ **figure 36**
the symbol for double insulation

Fuses and circuit breakers Experiment 4

The meter cabinet contains various safety features (figure 37).
To start with, each circuit has its own **circuit breaker** or **circuit fuse**. If the current in a circuit exceeds 16 A, the circuit breaker will turn off the power. This prevents the wires from becoming so hot that they become a fire hazard.



▶ **figure 37**
This is what you find in the meter cabinet.

Modern domestic systems use electronic fuses called **circuit breakers**. These circuit breakers have a lever which ‘flips’ when the power is turned off (figure 38). This lets you see which circuit the fault is in straight away. Once the fault has been fixed, you can switch on power again by flipping the lever up.

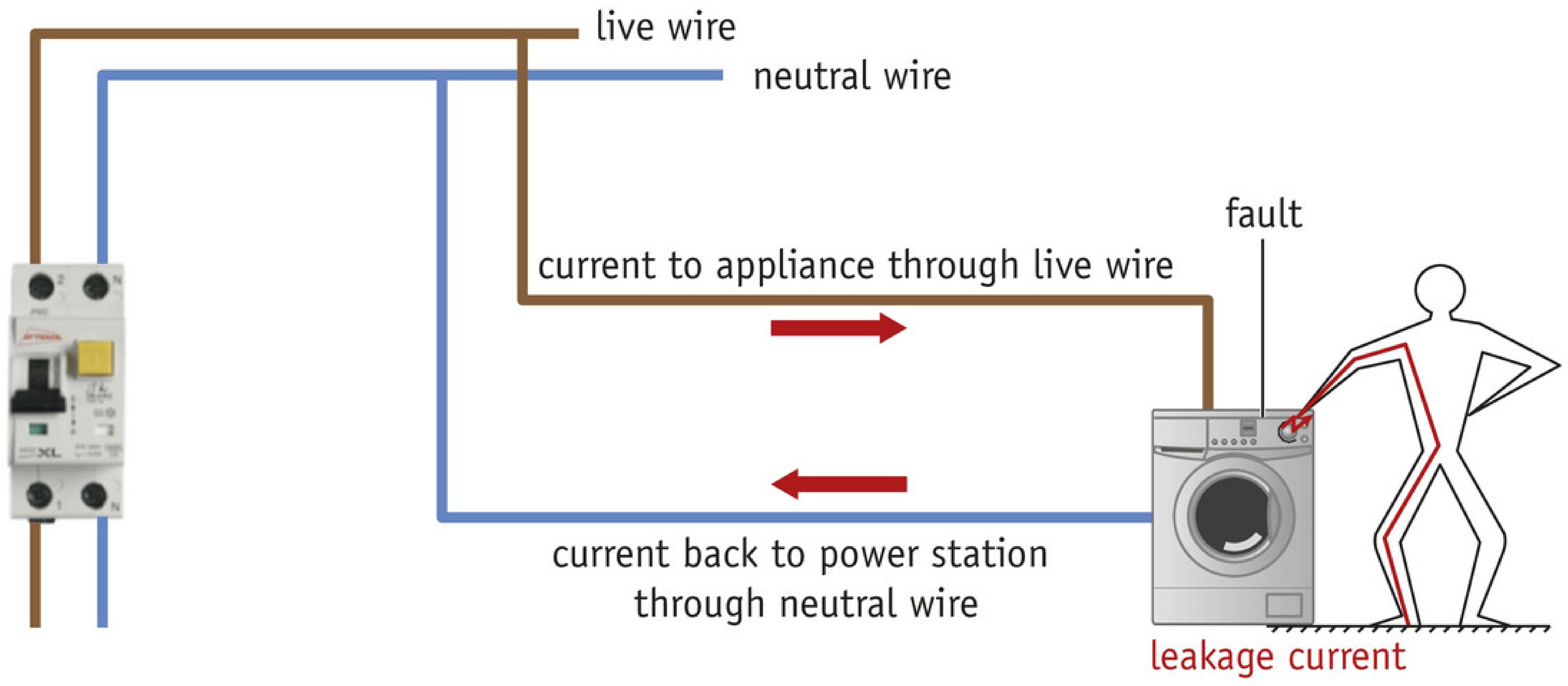
◀ **figure 38**
a row of circuit breakers

Earth leakage circuit breaker

Apart from fuses, the meter cabinet also has one or more **earth leakage circuit breaker(s)** (ELCB – see figure 39).
An earth leakage circuit breaker compares the current in the live wire (colour) with the current in the neutral wire (blue). If the two currents are equal – as they normally should be – the ECLB will let the current pass.

▲ **figure 39**
Use the test button to check whether the earth leakage circuit breaker is working properly.

Figure 40 shows a drawing of a situation in which the two currents are different. The metal outside of the appliance has become live because of a defect in the insulation. As a result, current 'leaks' when someone touches the appliance. The current in the neutral wire is now less than the current in the live wire.

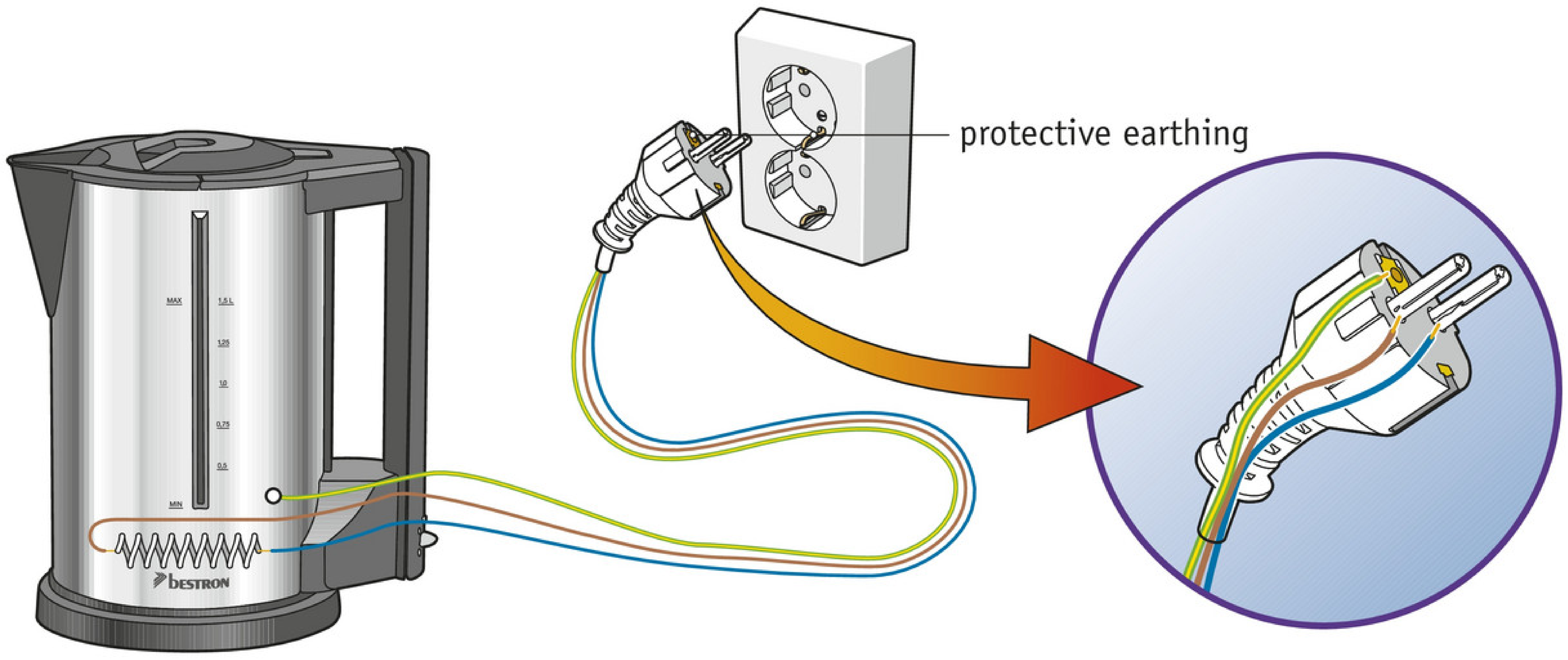


▶ **figure 40**
The ELCB turns off power when there is a leakage current.

If the difference in current exceeds 30 mA, the earth leakage circuit breaker will turn off the power. This means that the current can not leak through your body (or anything else). If you touch the appliance, you will get a shock, but that is all: the power is turned of almost at the same moment.

Earthing

You do not actually want the leakage current to be passing through anyone's body. That is why appliances are often earthed. A yellow-green **earth wire** runs from the outer casing of the appliance via the flex to the earth pin – the outer edge of the socket (figure 41). The earth wire then goes from the socket to the **earth rail** in the meter cabinet. From there, it is in turn connected to a metal pin that is hammered deep into the ground.

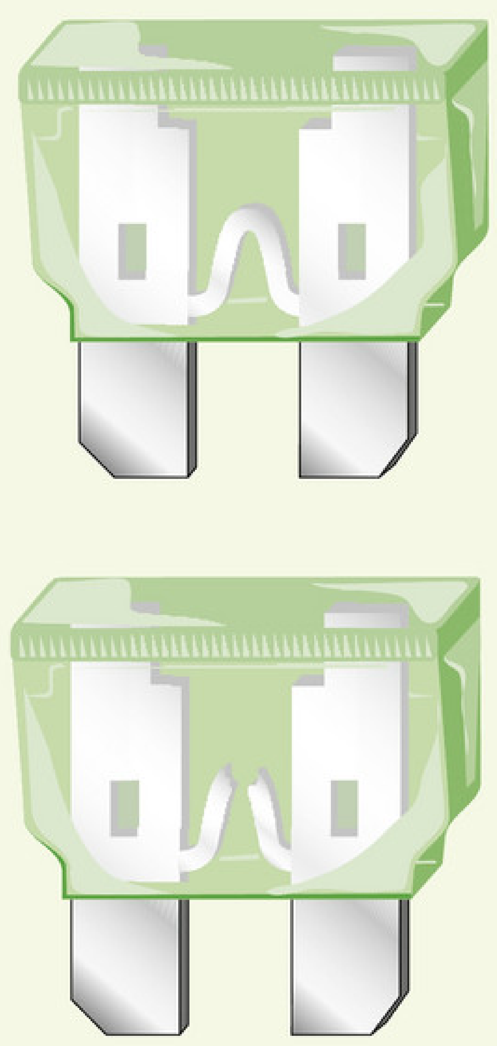


▶ **figure 41**
This is how a kettle is earthed.

If the metal casing of the appliance becomes live, a substantial leakage current then goes into the ground via the earth wire. This means that the ELCB turns off the power immediately. In that case, you do not have to wait until the leakage current occurs by accident, for instance when someone touches the appliance.

Before earth leakage circuit breakers existed, the leakage current to the earth had to make the circuit's fuse blow. That did not always work: sometimes the leakage current remained well below 16 A and nothing happened. A modern ELCB may be tripped by a current of as little as 30 mA. This provides additional safety, which cannot be ensured by a fuse.

Plus Car fuses



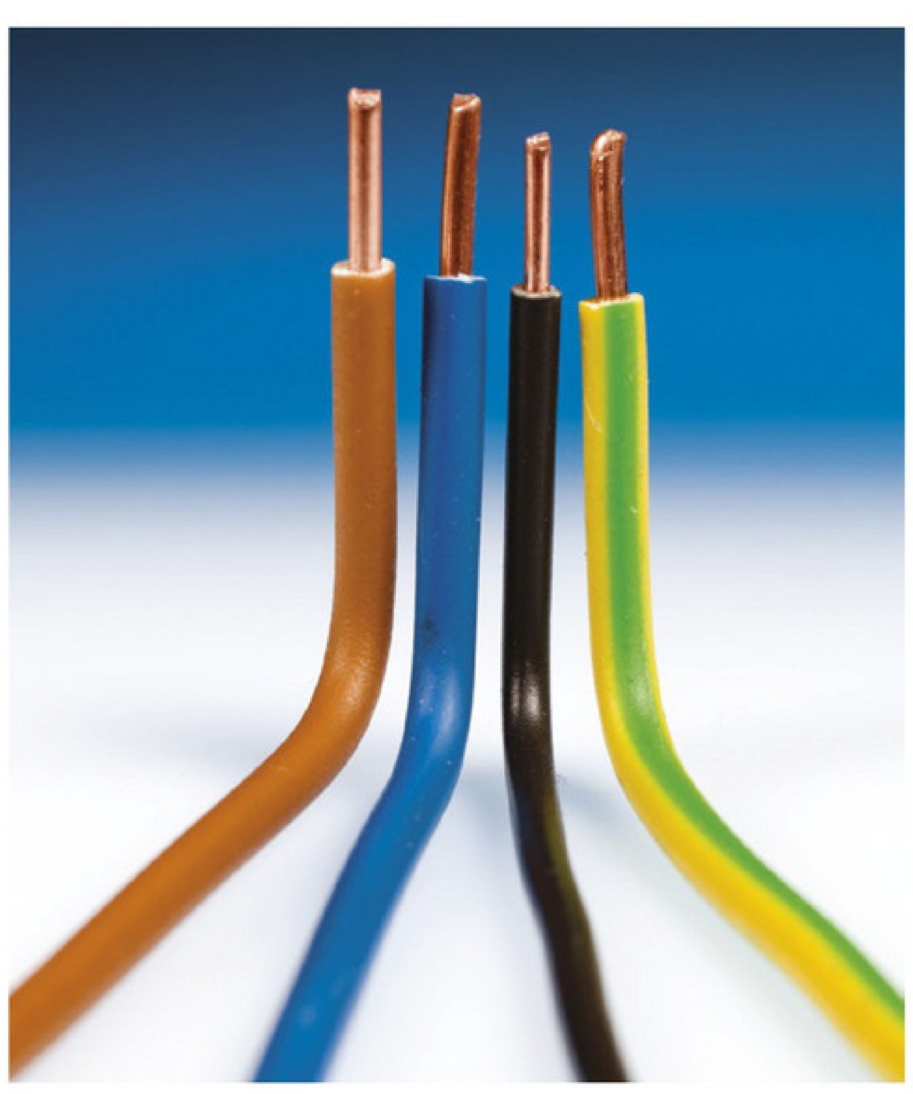
▲ **figure 42**
fuses in a car ready for use (top) and blown (bottom)

A car has dozens of parts that work on electricity: the starter motor, the fuel pump, the windscreen wipers, the head lights, the rear window heater, the horn, etc. Separate circuits are provided for each electrical part, with a fuse of its own.

Most cars use **pull-out fuses** (figure 42). A pull-out fuse blows (melts) when the current through the circuit gets too high. This prevents the wires from getting too hot and making the car catch fire.

Not much current runs through the low-power components such as dipped headlights. These components are protected by a 'small' fuse, e.g. a 10 A fuse. The rear window heating is at a much higher power. It is secured by a 'heavy duty' fuse, such as e.g. a 25 A fuse.

Exercises



▲ **figure 43**
the four types of wire in a domestic electrical installation

35 Answer the questions below.
- **a** How can you tell that an electronic fuse has switched off the power in the circuit?
- **b** Why is it important for an earth leakage circuit breaker to determine whether it should switch the power off or not?
- **c** How can the metal exterior of an electrical appliance become live?
- **d** In what situation does an earth leakage circuit breaker provide greater security than a fuse?

36 You will find four types of wires in each domestic electricity systems (figure 43).
- **a** State the colour/colours of each type of wire and write down the name.
- **b** What type of wire is intended for discharging a 'leakage current'?
- **c** Explain the path that the leakage current is discharged along in that case.

37 If you take hold of a 230 V wire, you will get a severe shock. Your hands may become sweaty from the fright.

a How does this change the current through your body?

b It will become more difficult then to let go of the wire.
Why?

38 Three appliances are switched on in the kitchen of Peter's apartment: the washing machine, the electric oven and the fridge. There is a power failure when Peter switches on his kettle.

a Write down two possible causes for this power failure.

b The television in Peter's living room is still on.
Why is there no power failure there?

c Peter sees that the lever of one of the circuit breakers has flipped. When he pushes the lever up and releases it, it flips back down.
What should Peter have done first?

39 Amelia is doing her homework. When it gets dark, she presses the switch of her desk lamp. She is annoyed when the lamp does not turn on.

a Give three possible causes for this.

b Amelia looks outside. The lights in other houses are on everywhere in the street.
What possible cause can she therefore exclude?

c Amelia turns on the computer on her desk. It starts up immediately.
What other possible cause can she therefore exclude too?

d What possibility is the only one left now? How can Amelia test if this is really the cause?

40 Five situations are described below.

1. Beatrice tries to operate three appliances (together 4.2 kW) on one circuit.
2. Lisa suddenly gets a shock when she touches a broken kettle.
3. Loose wiring has caused a short circuit in Gemma's television.
4. Ingrid touches the earth pin of an earthed socket.
5. Jessica drops the hairdryer (which is on) into the bathtub, which is still full of water.

In which situation (or situations):

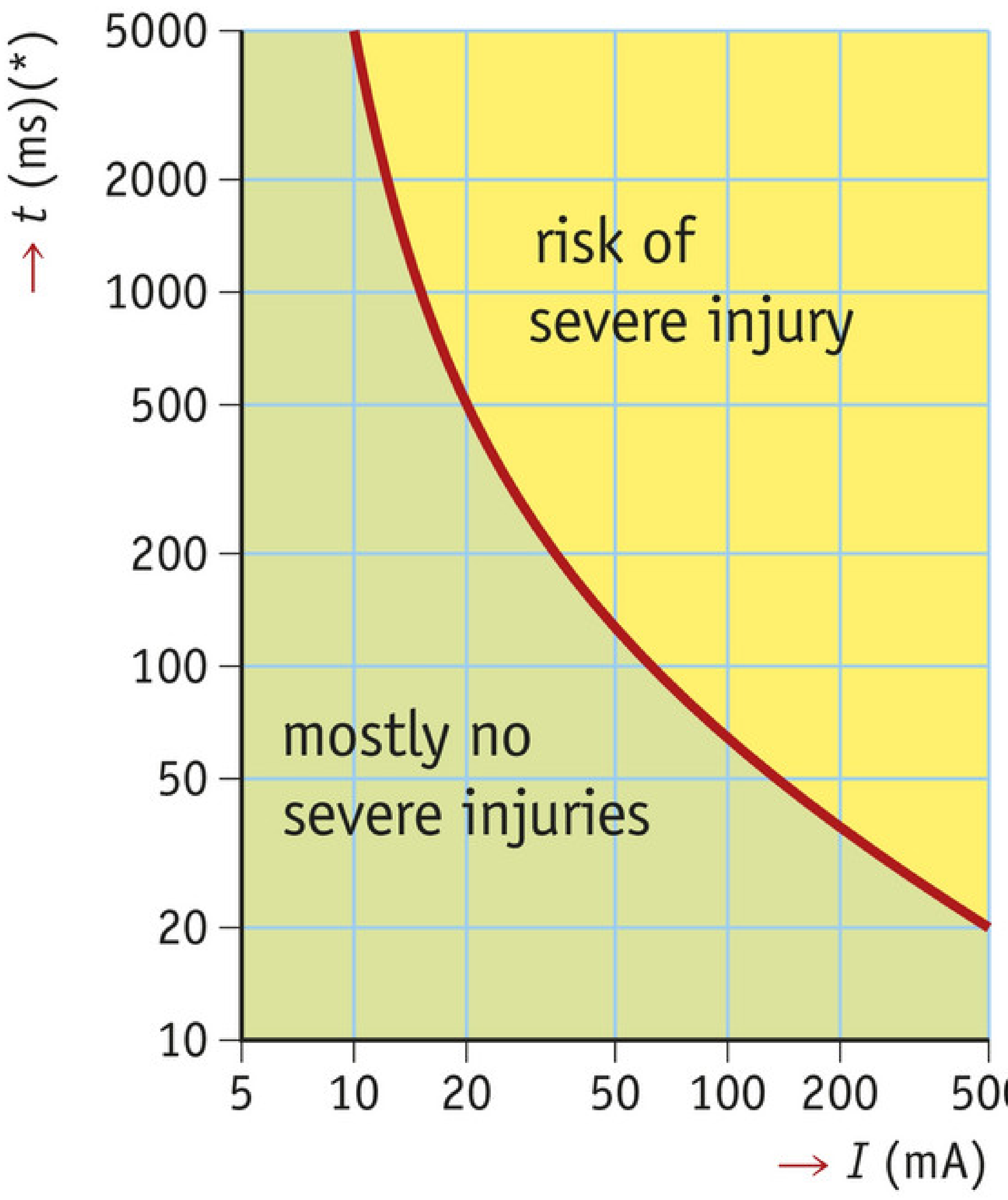
a will the circuit fuse interrupt the circuit?

b will the earth leakage circuit breaker interrupt the circuit?

c will nothing happen, as there is no hazard?

41 Explain:
- **a** why it is important that the metal casing of a washing machine is earthed.
- **b** why there is no point earthing the outer casing of a double-insulated appliance.

42 David gets a shock, when he touches his electric oven. A current of 8.25 A is running through the live wire at that moment and a current of 8.21 A through the neutral wire.
- **a** Determine the size of the leakage current in this situation.
- **b** Explain if the earth leakage circuit breaker will switch off power.
- **c** When the oven is repaired the following day, it turns out that the earth wire has come loose. As a result, the metal outer casing of the appliance was not earthed anymore.
  Explain why David would not have got a shock, if the earth wire had been attached properly.



▲ **figure 44**
the risk threshold for an electric shock

43 An electric shock may cause serious injuries. The level of risk depends both on the current and on the time the current runs through the body (figure 44).
- **a** Within how long must an earth leakage circuit breaker turn off the power to limit the risk:
  - at a current of 20 mA?
  - at a current of 200 mA?
- **b** The website www.veiligheid.nl states: “The earth leakage circuit breaker switches off when the leakage current is greater than 30 milliamps and continues for at least 20 milliseconds, thereby making electrocution impossible.”
  Is this statement correct if you look at the information in figure 44? Explain.

***44** Giles is checking if a socket is live. The neon bulb in the voltage detector lights up when he presses the back end of the voltage detector with his finger (figure 45).
- **a** Is the current that runs through the neon bulb and his finger to the earth strong? How do you know that?
- **b** Giles notices that the neon bulb lights up more brightly, when he touches a water tap with his other hand.
  Why does the current increase? Use the word ‘resistance’ in your explanation.
- **c** Is the piping in Giles’ house made of copper or plastic? Explain your answer.

◀ **figure 45**
testing a socket using a voltage detector

Plus Car fuses

45 The power of a car headlight is 60 W and it works on a voltage of 12 V.

a Calculate the current through the headlight.

b The circuit for the headlight is protected by a 10 A fuse.
Explain what is meant by a '10 A fuse'.

c The current that would make the fuse to melt is higher than the current that normally runs through the bulb.
Explain why this is necessary.

46 Table 4 contains information about a number of car components.

a Copy table 4 into your exercise book. Calculate the current that runs through each part. Write down your results in the table.

b Pick a suitable fuse for each component. Choose between these five options for each of them:

- fuse 1: 5 A
- fuse 2: 10 A
- fuse 3: 15 A
- fuse 4: 20 A
- fuse 5: 30 A

▼ **table 4** electrical data for car components

component	data	current (*)	fuse
horn	12 V, 80 W		
windscreen wipers	12 V, 150 W		
left headlight	12 V, 60 W		
right headlight	12 V, 60 W		
reversing lights	12 V, 30 W		
fog lights	12 V, 200 W		
rear window heating	12 V, 300 W		
engine electronics	12 V, 45 W		
fuel pump	12 V, 220 W		
air conditioning	12 V, 320 W		

(*) Under normal conditions, if everything is working properly.

Experiments

Experiment 1 The transformer 30 min

Introduction
The voltage from a voltage source is often either too high or too low. In such cases you have to use a transformer. A transformer lets you transform the voltage up or down, while hardly any electrical energy will be lost.

Aim
You are going to investigate the properties of a transformer.

Requirements
- power supply box
- soft iron yoke piece
- soft iron breech piece
- coil with 300 windings
- coil with 600 windings
- voltmeter or multimeter
- copper or aluminium rod
- wires

Doing the experiment and writing it up
- Build the simple transformer that is shown in figure 46.
- Carry out the four experiments that are described below.
- For all the experiments, set the power supply box to 6 V (~ or =).

Investigation 1
- Investigate whether it is possible:
  - to transform a direct voltage;
  - to transform an alternating voltage.

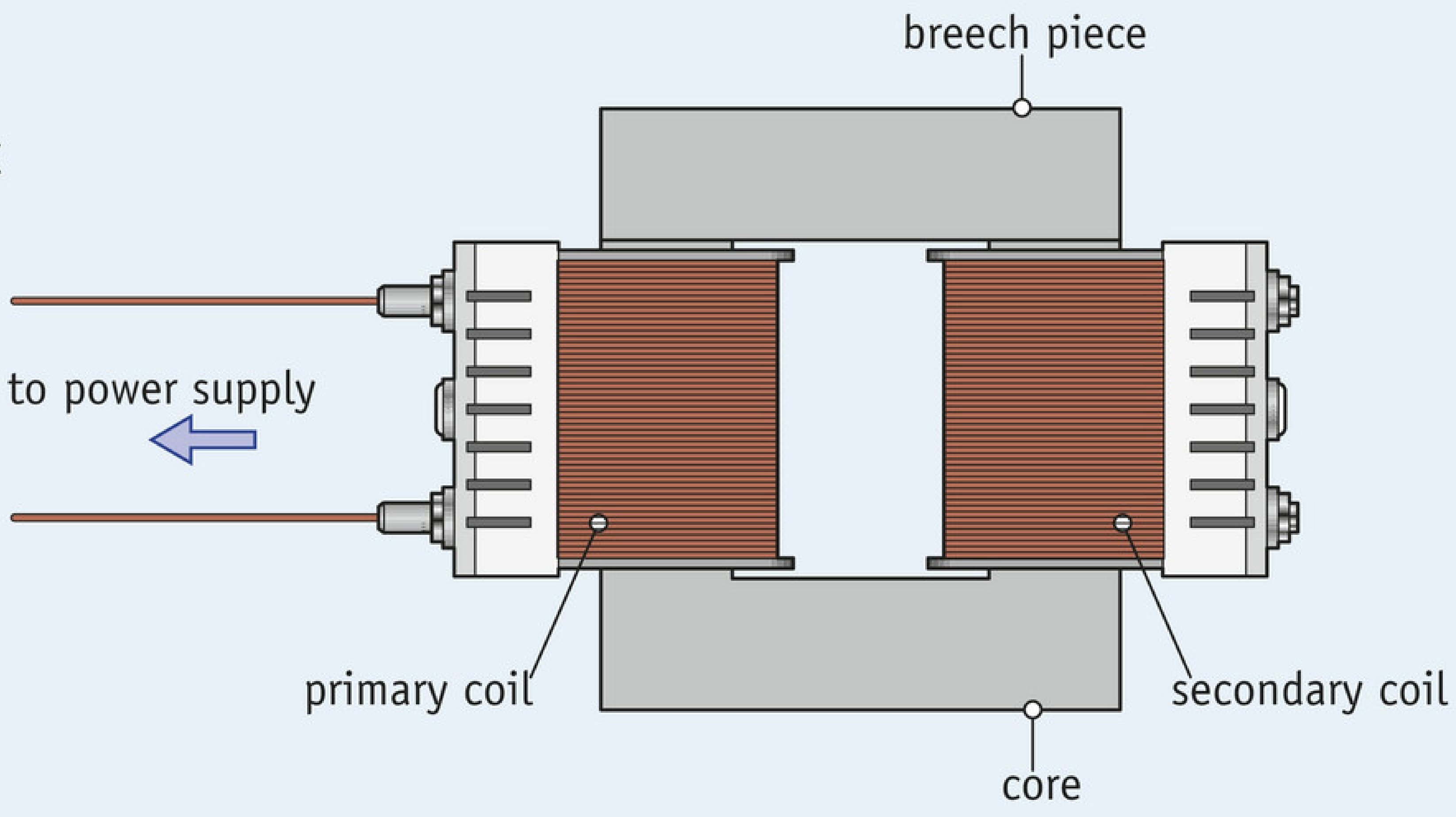
Investigation 2
- Investigate how you can step a voltage of 6 V upwards. Which coil must you use as the primary coil and which as the secondary coil? What will the secondary voltage be?

Investigation 3
- Investigate how you can step a voltage of 6 V downwards. Which coil must you use as the primary coil and which as the secondary coil? What will the secondary voltage be?

Investigation 4
- Investigate what happens if you remove the breech piece. Does the secondary voltage change, and if so, how? What happens if you replace the breech piece with a copper or aluminium rod?

1 Write down your conclusions after each investigation.

- Your teacher will tell you which investigations you have to write up a report on.



▲ **figure 46**
a simple transformer

Experiment 2 Measuring using a kWh-meter 30 min

Introduction
A kWh-meter is used to measure the energy consumption of an electrical appliance. Normally, energy consumption can be read off from the counter, but this is difficult for small amounts of energy. That is why this experiment will teach you another measuring method.

Aim
You are going to determine the power of an appliance using a kWh-meter.

Requirements
- kWh-meter
- various electrical appliances
- stopwatch

Doing the experiment and writing it up
Measuring
A kWh-meter has a disc that starts to rotate when electrical energy is consumed. The counter in the meter is driven by this disc. The kWh-meter states a number C. When the disk has gone round this number of times, 1 kWh = 3600 kJ of electrical energy will have been consumed.

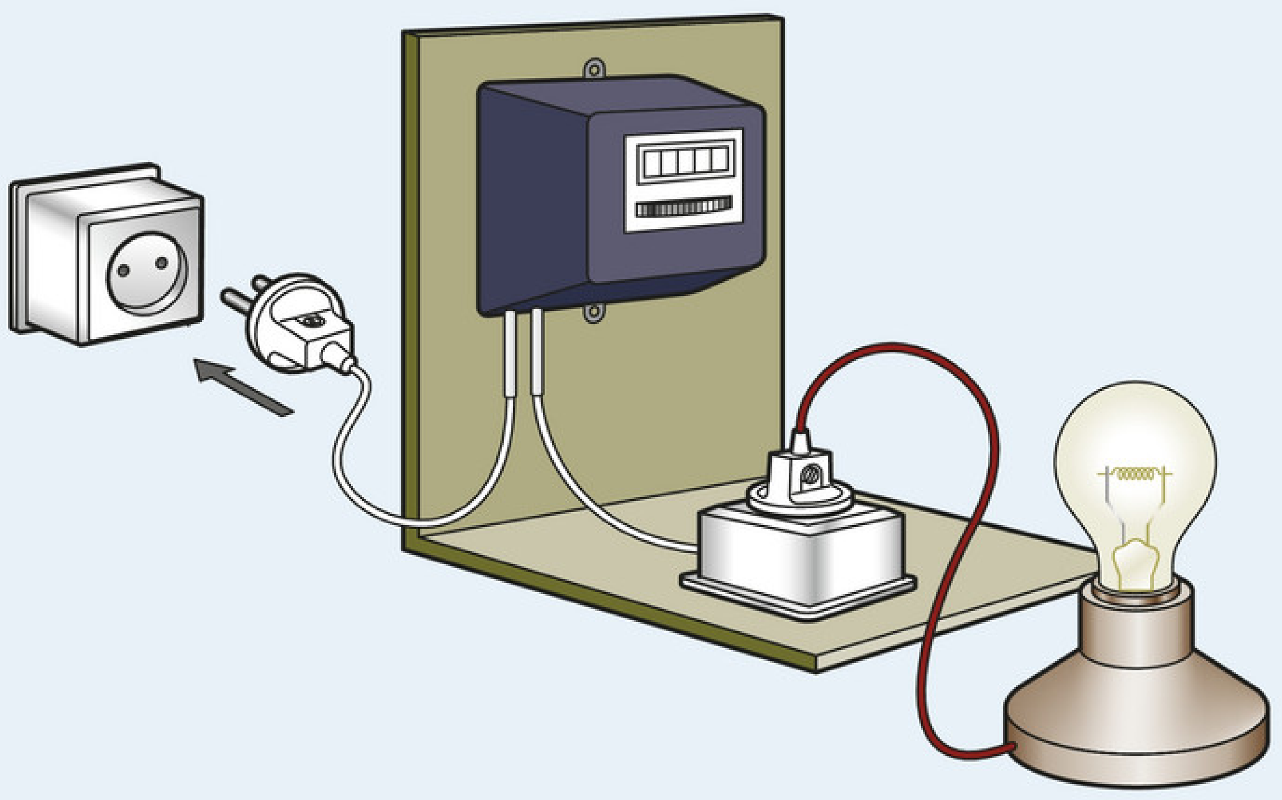
1 Write down the number C that is stated on the kWh-meter.

– Choose an electrical appliance and look at its type plate.

2 Write down the power stated on that type plate.

– Connect the appliance to the kWh-meter (figure 47). Turn on the appliance.
– Measure how long the disk of the kWh-meter takes to rotate ten times.

3 Write down the time that you have measured.
4 Determine the power of the appliance using your measurements. Compare the results with the information on the type plate and explain any differences.



▲ figure 47
the setup for experiment 2

Experiment 3 Measuring using a power meter 30 min

Introduction
A power meter is used to measure the power and energy consumption of electrical appliances. This measuring instrument is also known as an energy meter or an energy costs meter. Your teacher will give you (a link to) the manual. Read it well before you start working.

Aim
You are going to determine the power and energy consumption of various electrical appliances.

Requirements
- power meter
- kWh-meter
- hair dryer
- stopwatch
- kettle
- electric heater

Doing the experiment and writing it up

WARNING
In this experiment, you will be working with a voltage of 230 V. So be careful. Follow your teacher's instructions.

– Your teacher will tell you what measurement(s) you are going to perform.

Measurement 1: The power of a hair dryer
– Insert the power meter into a socket.
– Connect the appliance to the power meter.

◀ **figure 48**
This is how the power consumption of a hair dryer is measured.

– Determine the power consumption of the hair dryer at various settings (figure 48).

1 Write down the results of your measurements.
2 Write down the power stated on the type plate of the hair dryer.
3 Compare the power stated on the type plate (question 2) with the power values that you have measured (question 1).
What is your conclusion?

Measurement 2: The energy consumption of a kettle
– Set the latest electricity costs on the power meter.
– Put half a litre of water in the kettle.
– Measure the amount of electrical energy that is needed to bring half a litre of water to the boil.

4 Write down:
- how long it took to bring the water to the boil;
- how much electrical energy the kettle consumed;
- how much this amount of energy would cost.

5 Calculate the energy consumption of the kettle using the power on the type plate and the period of time that you wrote down in question 4.
6 Compare the calculated energy consumption (question 5) with the measured energy consumption (question 4).
What is your conclusion?

Measurement 3: Checking the power meter
A kWh-meter has a disc that starts to rotate when electrical energy is consumed. The counter in the meter is driven by this disc. The kWh-meter states a number C. When the disk has gone round this number of times, 1 kWh = 3600 kJ of electrical energy will have been consumed.

7 Write down how many times you want the disk of the kWh-meter to go round.
8 Calculate how many kilowatt-hours this number of revolutions corresponds to.

– Connect the kWh-meter to the power meter.
– Connect the heater to the kWh-meter.
– Turn on the heater and wait until the kWh-meter disc has gone round the agreed number of times. Meanwhile, measure the energy consumption using the power meter.

9 What is the energy consumption according to the power meter?
10 Compare the energy consumption according to the kWh-meter (question 8) with the energy consumption according to the power meter (question 9).
What is your conclusion?

Experiment 4 Making a fuse 30 min

Introduction
A cut-out is a simple kind of fuse. The most important part is a short piece of wire that the current runs through. When the current through the wire gets too high, the wire melts. This will switch off the power.

Aim
This experiment shows you how a circuit is protected by a simple fuse.

Requirements

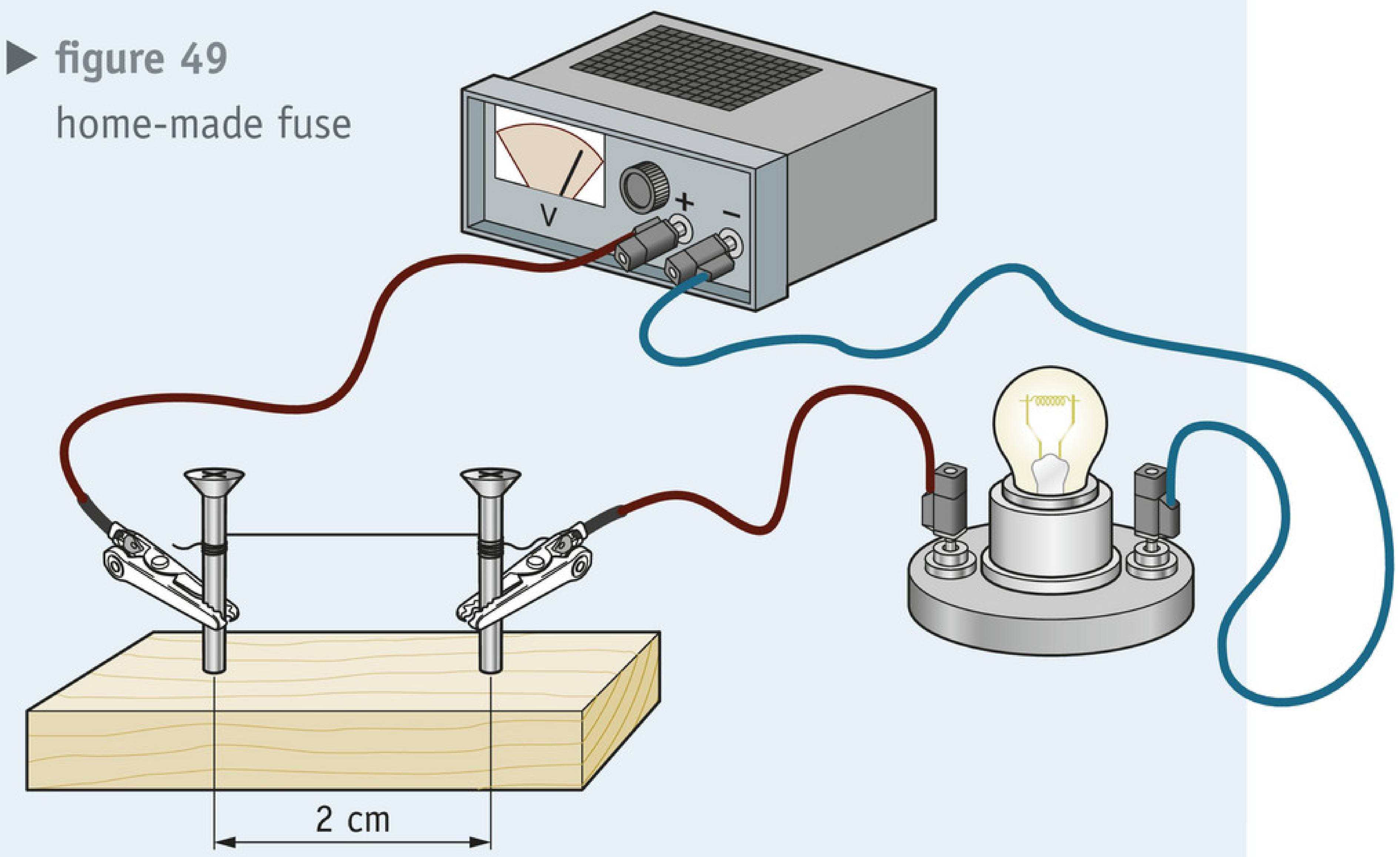
- power supply box
- 2 crocodile clips
- bulb
- 4 wires
- piece of wood
- 2 nails
- iron wire

Doing the experiment and writing it up

- Make the fuse as drawn in figure 49.
- Switch the power supply box on. Set the voltage to 6 V.
- Connect first the bulb and the fuse to the power supply box.
- You have one wire left. Use this wire to short the bulb. The current must be able to take another route: not through the bulb, but through the (extra) wire. Meanwhile, have a good look at what is happening.

1. Describe accurately what you have observed.
2. Draw the diagram of the shorted circuit.
3. In the event of a short circuit, the current can take an 'easy' route with very little resistance. What was this 'easy' route in this experiment?
4. Explain in your own words how the cut-out fuse has protected the circuit.

▶ **figure 49**
home-made fuse



Experiment 5 Carrying out research: saving energy 40 min

Introduction

Imagine: the packaging of an energy-saving bulb gives a comparison with a normal incandescent bulb. You can conclude from this that an energy-saving bulb is at least five times as economical as a standard incandescent bulb. You might wonder if this statement is correct. How can you check this?

Aim

You are going to look for an answer to the following study question:
Is an energy-saving bulb 5× as economical as an incandescent bulb with the same light output?

Requirements

For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up

- Think how you can give the most reliable answer to the question. What is your test setup going to look like; what exactly are you going to look up; how will you make sure that the measurements are repeatable and can therefore be verified?

1. See 'Skills 1' at the back of the book. Make a work plan for this study.

- The work plans will be discussed with the rest of the class at the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2. Write down all the measurements, calculations and results in your exercise book.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

◀ **figure 50**
Is the claim on the packaging correct?

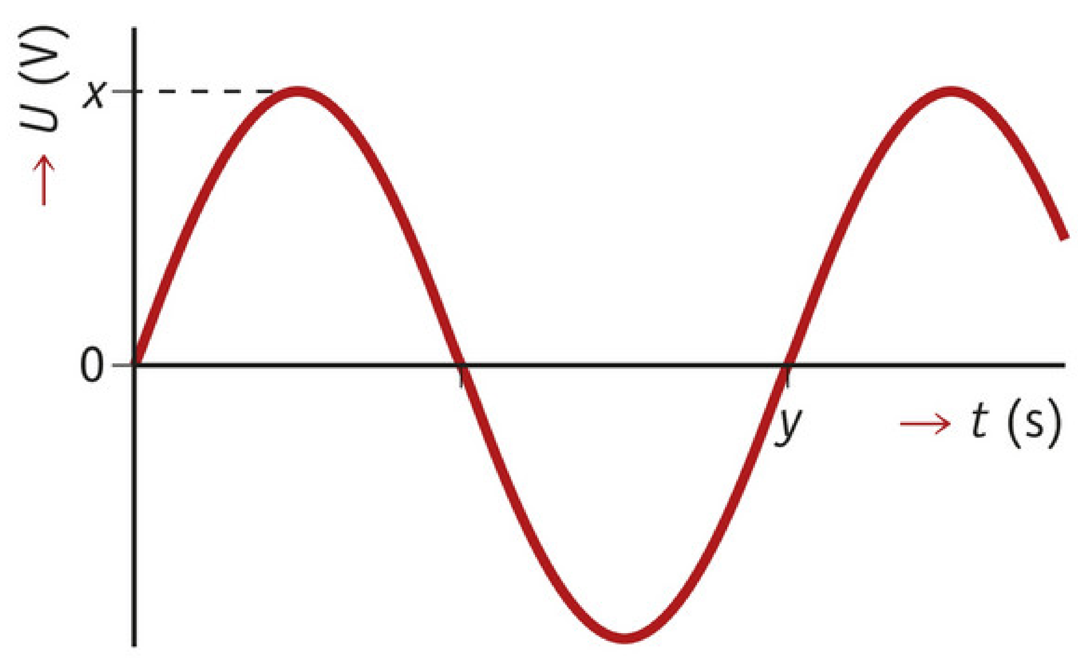
Test Yourself

You can also do questions 1 to 16 on the computer.

1 Copy and complete:
- **a** Energy loss is created in the cables of the electricity grid because the electrical energy is partially converted into … .
- **b** To limit the energy loss, electrical energy is best transported at the … voltage possible.
- **c** The voltage that is supplied by the … at the power station is therefore stepped … immediately.

2 Figure 51 is a graph of the mains voltage. What value do the numbers x and y have in the graph?

A $x = 230$ $y = 0.01$
B $x = 325$ $y = 0.01$
C $x = 230$ $y = 0.02$
D $x = 325$ $y = 0.02$



▲ **figure 51**
mains voltage

3 Albert is doing a series of experiments using a transformer. The transformer has two coils, A and B. Coil A has 100 windings, coil B has 400 windings.
- **a** In his first experiment, Albert connects coil A to an alternating voltage of 4.5 V. What is the voltage supplied by coil B?
- **b** In the second experiment Albert works the other way round. This time he connects coil B to an alternating voltage of 4.5 V. What is the voltage supplied by coil A now?

4 A halogen bulb (12.0 V/0.40 A) has been connected to the mains (230 V) using a suitable transformer. The primary coil of the transformer has 690 windings.
Calculate the number of windings of the secondary coil.

5 Copy and complete:
- **a** 45 MJ = … kWh
- **b** 1800 kJ = … kWh
- **c** 4.5 kWh = … MJ
- **d** 0.2 kWh = … kJ

6 A website states the following information about a fan heater:

> The QH20 Plus with anti-tilt locking feature has two heating positions: 1.0 kW and 2.0 kW.

Calculate the current through the appliance when it is in the highest setting.

7 The fan heater in exercise 6 is set to its highest position for 6.0 min.
Calculate the energy consumption of the heater in joules and in kilowatt-hours.

8 Ralph hoovers the entire house from top to bottom in an hour and fifteen minutes. The power of the vacuum cleaner is 1200 W.
- **a** Calculate how much electrical energy the vacuum cleaner has consumed during that time.
- **b** Calculate how much Ralph has to pay for this electrical energy. 1 kWh costs € 0.22.

9 Nicole wants to know if an earthed socket is live. She inserts a voltage detector into the socket, first in the left-hand hole and then into the right-hand one. The first time, the neon bulb in the voltage detector does not light up, the second time it does.
- **a** Which wire did the voltage detector make contact with the first time?
- **b** Which wire did the voltage detector make contact with the second time?
- **c** Finally, Nicole holds the voltage detector against the earth pin of the socket. Is the neon bulb lit now, if everything has been connected properly?

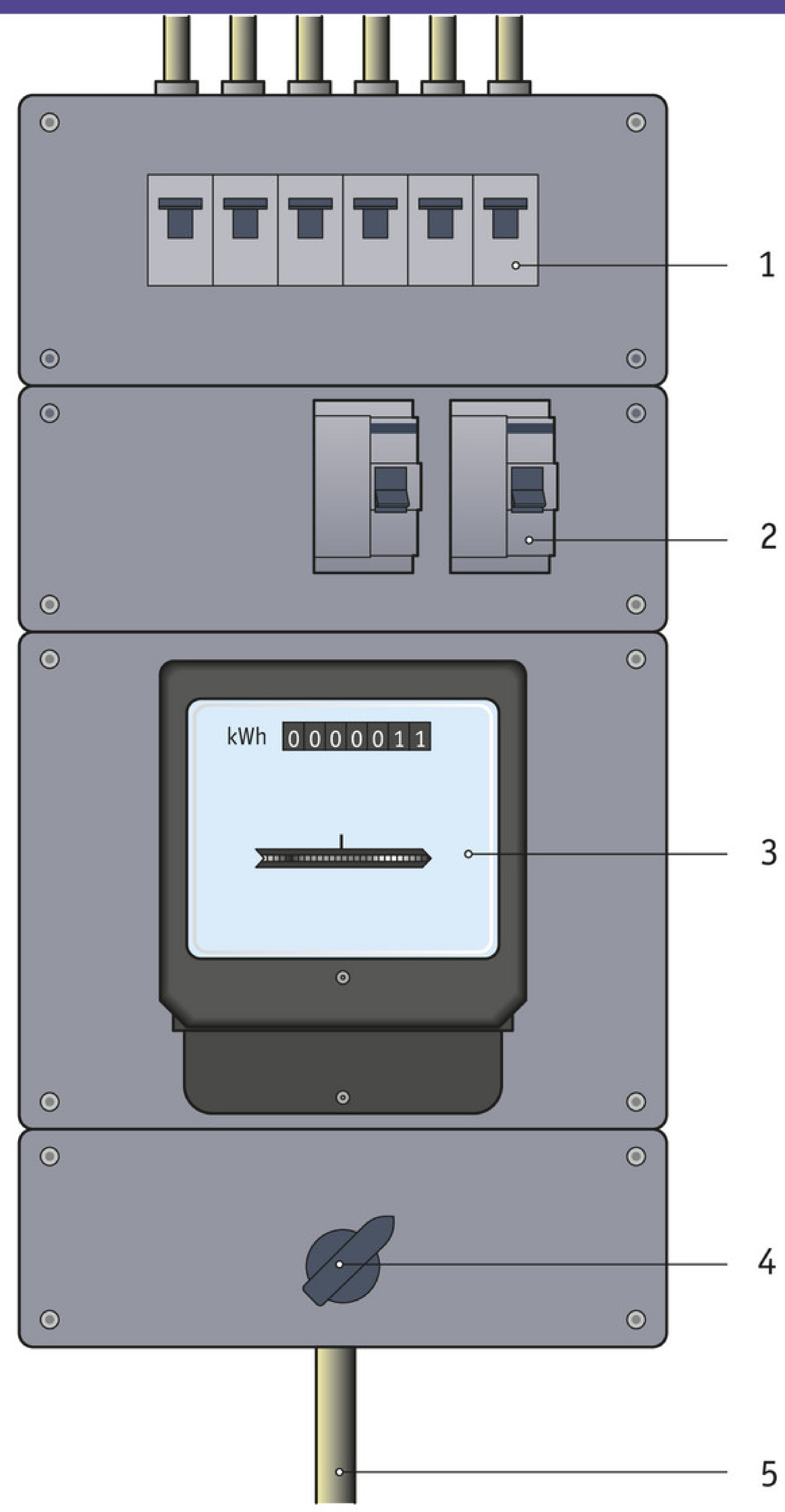
10 On an annual basis, a 2400 W tumble dryer consumes 432 kWh.
How many hours is the dryer used for each month on average?

11 Natalie has a computer (450 W), a desk lamp (12 W) and a fan (60 W) that are connected to a socket using an extension cable. The maximum current that is permissible through the extension cable is 6 A.
What is the current when all the appliances are on?

12 Continuation of exercise 11.
Natalie also connects a vacuum cleaner to the extension cable. This makes the current that flows through the extension cable rise to 10 A.
What effect could this have?
A Nathalie could get an electric shock if she touches the cable.
B The high current could damage the computer.
C The power may cut in and out irregularly.
D The cable could get so hot that it might cause a fire.
E The earthing circuit breaker in the meter cabinet may blow.

13 Figure 52 shows the meter cabinet in a home.
a How many circuits does this domestic electricity supply have?
b Write down the numbers 1 to 5 below each other.
Write down the name of the labelled part after each number.

14 Read the newspaper report in figure 53.
Select the correct options.
There is short circuit in an electrical blanket.
It means that the resistance of the blanket has suddenly become *higher / lower*. As a result, the current through the blanket became *higher / lower*.
Normally, a *fuse / earth leakage circuit breaker* prevents a short circuit from causing a fire.
Apparently, the current was too *high / low* for the blanket, but still too *high / low* to make the *fuse / earth leakage circuit breaker* to 'flip'.



▲ **figure 52**
meter cabinet of a home

Short circuit electric blanket

NIJMEGEN – A short circuit in an electric blanket led to a bedroom in a house on Teersdijk burning out completely last Sunday night. The fire was discovered in time and the residents were able to get away easily. The rest of the house suffered considerable smoke damage and water damage.

▲ **figure 53**
a blanket that really was too warm

15 The insulation of Mr and Mrs Stone's freezer is broken. As a result, the metal outer casing of the freezer is live. When Mr Stone touches the freezer, a 50 mA leakage current runs to the earth. Fortunately, Mr Stone's meter cabinet has a device that switches off the power immediately.
What is the name of this device?
A the main switch
B the circuit fuse
C the earth leakage circuit breaker
D the kWh-meter

16 State whether each of the following statements is true or false.
a If your skin gets wet, the contact resistance (for the current that enters and leaves the body) is much higher.
b The effective value of an alternating voltage is always smaller than the maximum value.
c If the power of an appliance is variable, the minimum power is stated on the type plate.
d The circuit breakers in the meter cabinet make sure that short circuits cannot be created in the domestic electricity supply.
e The earth rail in the meter cabinet is connected to a metal pin that is hammered deep into the ground.

***17** In 2014, the site www.nuon.nl stated the following:

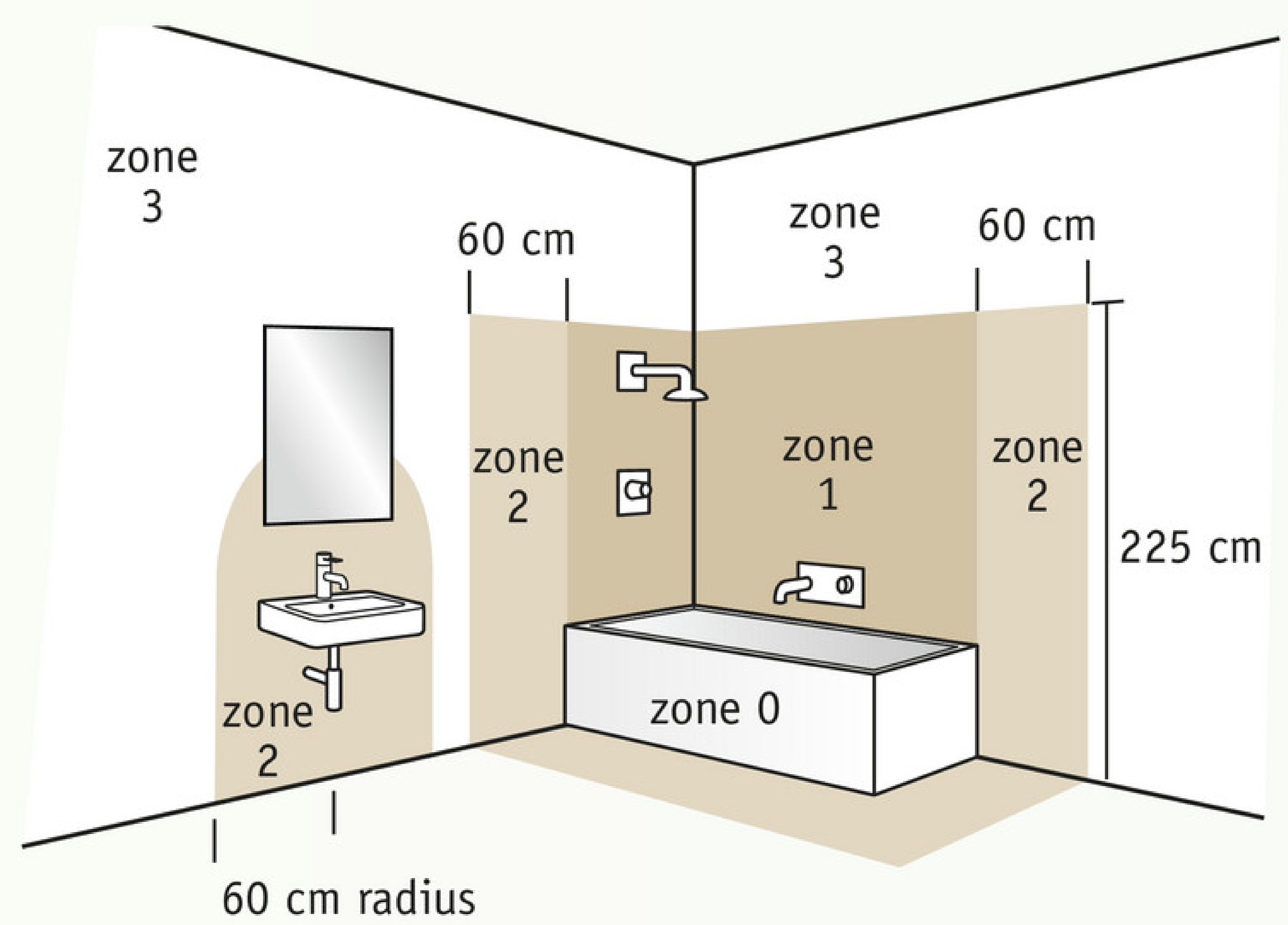
> Ask yourself whether you really need the clock on your microwave oven. If not, pull out the plug when you are not using the microwave. It will save you € 4 a year.

In 2014 you paid € 0.22 for 1 kWh.
Calculate the power of the clock.

18 Thomas and Lee are discussing the energy consumption of electrical appliances. Thomas says, "A 5 W bulb consumes less energy than a 1400 W drill." Lee believes that Thomas cannot say this just like that: "It depends."
Explain who is right and why.

***19** In the practical, Sylvia has a kWh-meter with a disk that goes round 1200 times per kWh. To determine the power of a toaster, she connects the appliance to the mains using the kWh-meter. The disk goes round 57 times in 3.0 minutes.
Use this information to calculate the power of the toaster.

20 The website of an energy company has a page about bathrooms (figure 54).
a Why must you not work on electricity at all in the bathroom?
b The bathroom is divided into three zones. Which zone has the greatest risk of accidents caused by electricity?
c Why must the light fitting in zone 2 be double insulated?
d Explain what is meant by 'double insulated'.



The bathroom is one area where you should not work on the electrics. Make sure that a qualified electrician sets up the electrical system: the only thing you should do yourself is select the furnishings.
Strict installation instructions are applicable to bathrooms. The bathroom is divided into three zones for this. Zone 1 is above the bath or the shower. Zone 2 is the space up to 60 cm away from the bath or shower and zone 3 is from 60 cm to 2.4 m away.
Sockets must not be placed in zones 1 or 2. Only lights with double insulation may be placed in zone 2. Special safety sockets only are allowed in zone 3.

▲ **figure 54**
safety first

A supergrid

Renewable energy is getting more and more important in Europe. There is enough sun, wind and hydroelectric power to provide the whole of Europe with electrical energy. When the wind is not blowing in Scotland, the Sun may well be shining in Spain. The only problem is how to get the energy to where it is needed. How can you transport renewable electricity from Spain to Scotland, when there is not enough in Scotland – or the other way round, when there is not enough in Spain? The European supergrid could be a solution.

for Europe

One disadvantage of renewable energy sources is that their output varies a lot. One day there may be a strong wind and the wind turbines are rotating happily. But the next day, there may be hardly any wind and the wind turbines produce nothing at all. Solar energy is only produced during the daytime, and the output can be much higher in summer than in winter.

As a result of all these fluctuations, countries can have an excess of renewable energy at one moment and a shortage the next. This is an awkward problem, because there still are no good ways of transporting the energy. Countries that have an excess cannot sell their surpluses to the rest of Europe. Countries that have a shortfall cannot import renewable electricity. That is why they decide to use their old, polluting power stations again...

The NorNed cable

The Netherlands and Norway are showing that things can also be done another way. In 2008 these two countries started to use the NorNed cable: a 580 km long, submarine high-voltage cable between Feda in Norway and the Eems harbour in the Netherlands. From that moment on, Norway has been able to supply electrical energy to the Netherlands, or the Netherlands to Norway – depending on what is the most advantageous.

Norway produces almost all its electricity as hydroelectric power from reservoirs. It is renewable and – often – very cheap. On the other hand, there may be major shortages in dry years. Electricity then suddenly becomes very expensive. There is a lot of natural gas in the northern part of the Netherlands and you find large power stations there. Although these do not produce sustainable power, they can supply electricity at any moment you choose.

There is a difference in energy consumption between the two countries too. At night, the Netherlands uses relatively little energy whereas the energy consumption in Norway is rather high at night. The Netherlands uses natural gas for heating, but Norway uses electrical heating, which takes a lot of energy in the winter.

Because of these differences, both countries can benefit from the NorNed cable. During the daytime, Norway can export inexpensive and clean *hydroelectric power* to the Netherlands. At night, the Dutch power stations can operate continuously and supply current into the other direction, to Norway. In dry years, the Dutch current helps prevent the Norwegians from being faced with shortages and extremely high energy bills.

HVDC technology

The high voltage power lines in Europe, and those in Norway and

NorNed technical data:

- cable length 580 km, of which 420 km is in shallow water (up to a depth of 50m) and 160 km at a depth of a maximum of 410 m
- total mass of cable: 47,000 tons
- mass of copper in the cable: 9,000 tons
- maximum voltages on the cable: +450 kV and −450 kV
- cable capacity: 700 MW
- construction costs: 600 million euros

the Netherlands too, use alternating voltages. It is an excellent system, if the distances are not too large. It works fine up to approximately 100 km. But problems arise with larger distances. So much energy will be lost in the cables that the energy transport costs more money than it brings in.

The NorNed cable uses a DC voltage. It is a HVDC connection, which combines *high voltage* with *direct current*. HVDC technology was chosen, because DC voltages are more efficient for large distances than AC voltages. This makes transporting electrical energy for hundreds of kilometres profitable.

HVDC has disadvantages too. The alternating voltage of the normal electricity grid has to be specially converted into VDC for the NorNed cable. At the other end, this DC voltage has to be converted back into an AC voltage. Technically, this is far from simple and requires a lot of equipment. The converter stations in Feda and the Eems harbour are each two football fields in size.

Technical perfection

The NorNed cable has a capacity of 700 MW, which is enough to provide one million households with electrical energy. This 700 MW goes through two copper cables with a diameter of only 3.5 cm. The cable also has insulation material, shielding and sealing. On the inside, the temperature gets up to 50 °C, but on the outside only up to a maximum of 35 °C.

A lot of advanced technology is used in the NorNed connection. That is why the connection is sensitive to faults. The cable had faults ten times in the first two years, sometimes for months at a time. There were several causes for these faults: broken cables, short circuits, defective components, software issues.
The teething troubles seem to have been overcome now. Economically, the cable has been a great success from the beginning. The trade in electricity between Norway and the Netherlands is running extremely well. The 600 million euros in construction costs had almost

been earned back by 2014, just six years after commissioning Nobody had expected this beforehand.

The future: a supergrid?

The success of the NorNed cable is not the only one of its kind. There are several other countries in Europe that have HVDC connections, such as France and Great Britain (2000 MW, 73 km), Greece and Italy (500 MW, 313 km) and Poland and Sweden (254 km, 600 MW).

According to some energy experts, this is only the beginning. One cable could transport up to 7000 MW across more than 2000 km using the current HVDC technology: the distance between Edinburgh in Scotland and Seville in Southern-Spain. Technically, this makes it possible to connect all the countries in Europe into one large European supergrid.

Such a *European supergrid* is good news for producers of sustainable energy. Europe wants to generate a large part of its electricity renewably. The supergrid makes this possible, because renewable energy can be imported and exported easily: it lets the national energy companies compensate for peaks and troughs in output much better.

But it is nowhere near that far yet. To start with, a lot of money is needed. The estimated cost of a supergrid is more than 125 billion euros. That is not an amount that can easily be paid by the countries in Europe. Agreements will have to be made about the use and management, which is not very simple when so many countries are involved.

Despite this, Tara Connolly, energy lobbyist of the environmental organisation Greenpeace, is optimistic: “A large proportion of the current grid is forty years old and will have to be replaced shortly. So we have to invest anyway – the question is then about the best way to spend our money.” She would choose a European supergrid without hesitating. Let us wait and see if Europe agrees with her.

Exercises

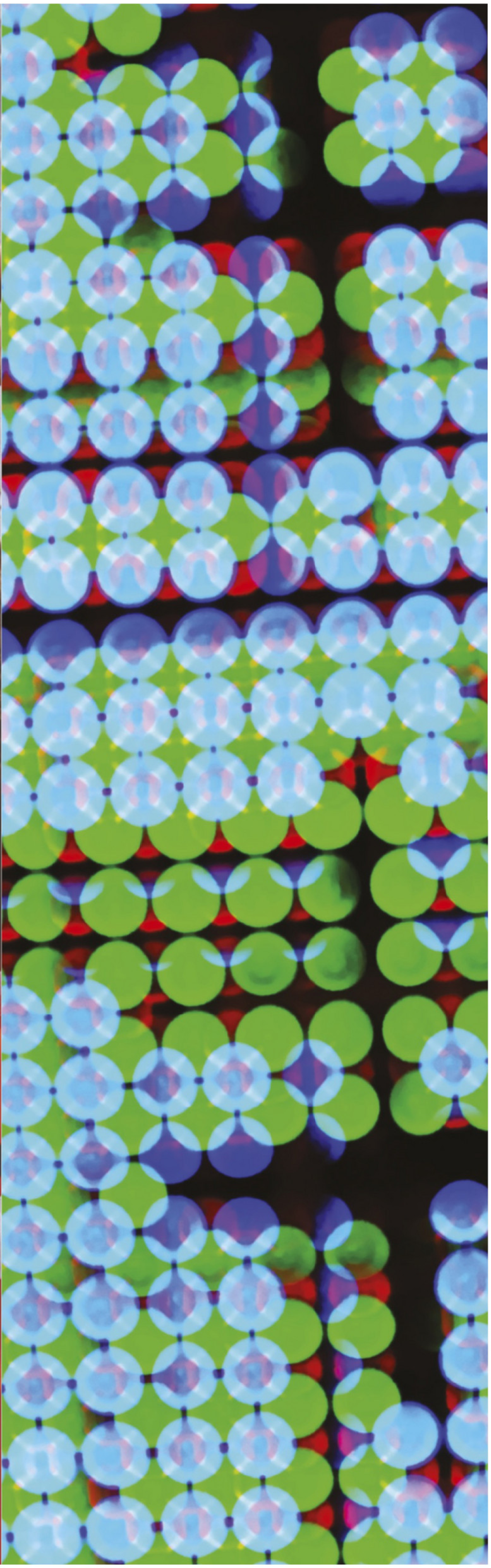
1 Calculate using the data in the text:
- **a** the (total) current that goes through the copper cables when the maximum capacity of the NorNed cable is being used.
- **b** the amount of electrical energy in kilowatt-hours that the NorNed cable can transport in one day from the Netherlands to Norway (or the other way round).

2 Explain why a relatively large amount of electrical energy is used in Norway at night.

3 HVDC (high-voltage direct current) technology has been used for the NorNed cable.
- **a** Why are HVDC cables used for long-distance energy transport instead of normal high voltage lines?
- **b** Why is HVDC unsuitable for the normal electricity grid, which distributes electrical energy to cities and villages?

4 It is technically possible to store a German surplus of wind energy temporarily in Norwegian reservoirs. There are plans to set up an HVDC connection between Germany and Norway.
Explain:
- **a** how you can store surplus renewable energy in a reservoir.
- **b** why the storage capacity is limited and not always constant.
- **c** how you can extract the stored energy from the reservoir again.


HOTEL
Heineken



3 Light and lenses

Creating images with light

Optical devices such as cameras, projectors and telescopes create images with light. To create such an image, the direction of the light has to be changed in a very specific way. Most optical devices use lenses to do this.

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1 Refraction

▲ figure 1
This effect is created by refraction.

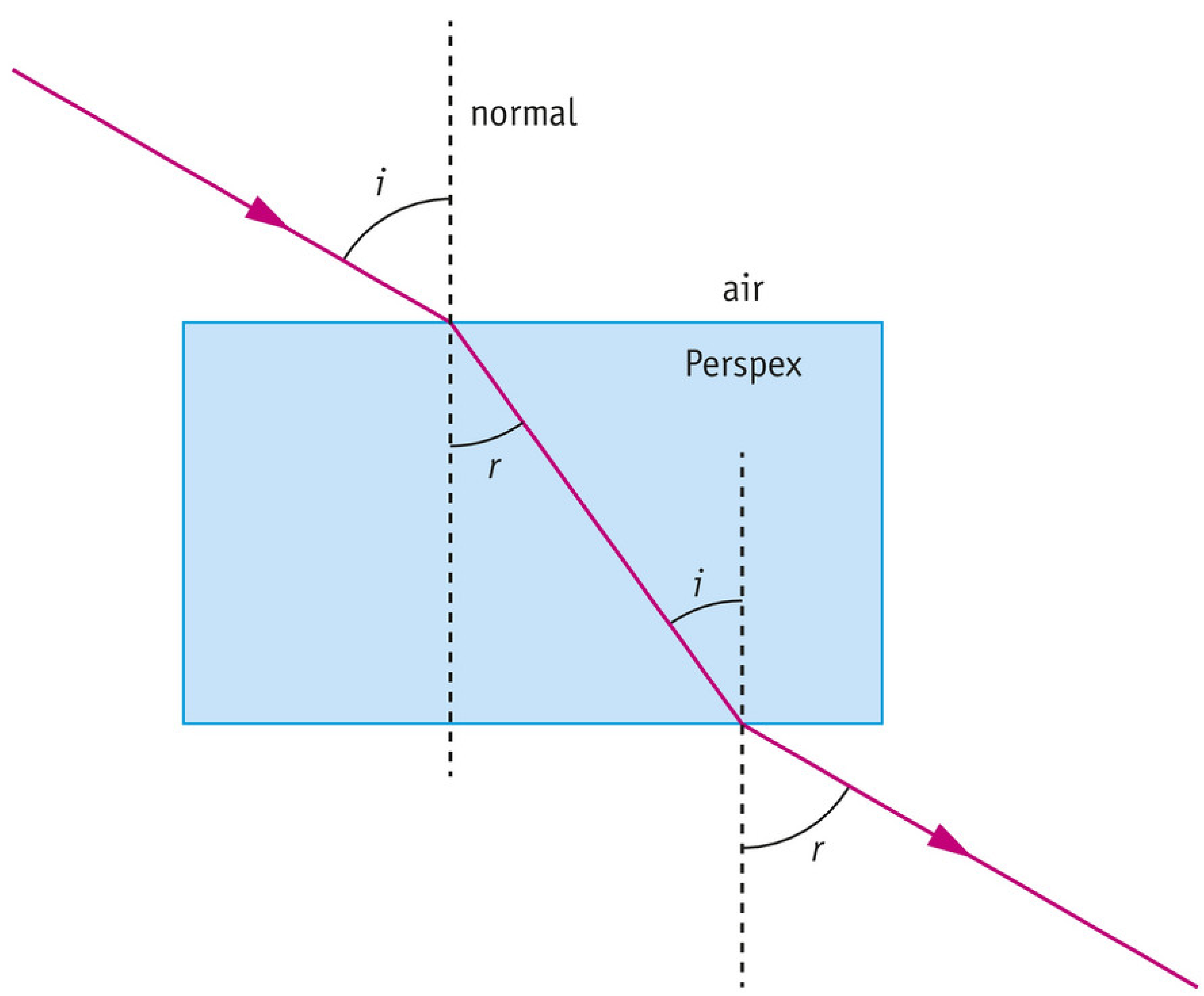
Mirrors, lenses and prisms are designed to change the direction of light. You can use them to steer the light in any direction you want. For instance, you can use the lens in a magnifying glass to focus the Sun's light onto a single point, making the temperature there rise a lot.

The angle of incidence and the angle of refraction

Experiment 1

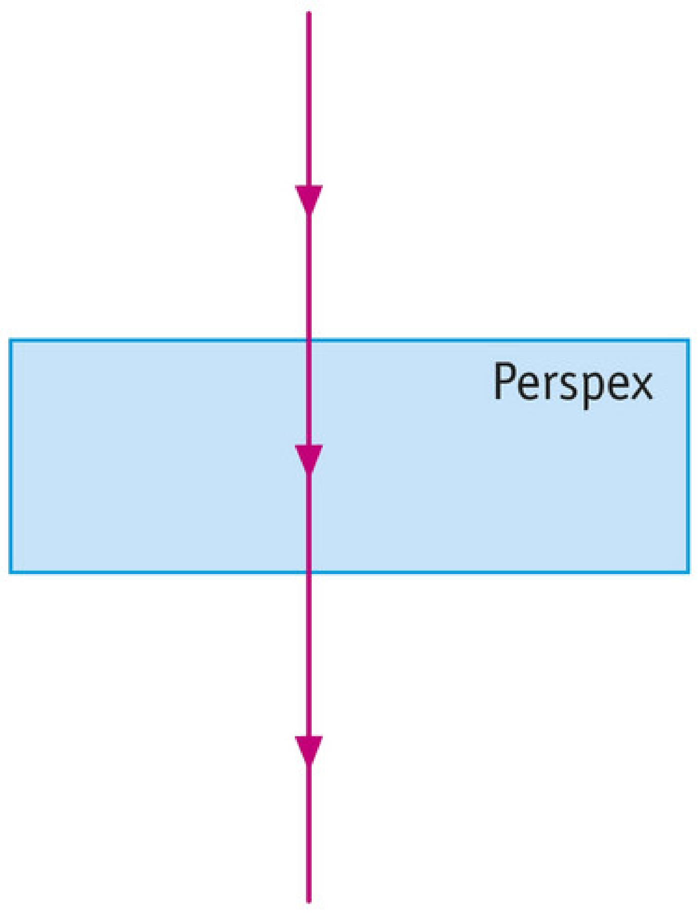
Light moves in straight lines. But when a thin beam of light – a ray – falls on the boundary layer between transparent substances, the rule no longer applies: the light then changes direction. This effect is called **refraction**. Figure 1 shows you an effect of refraction, you do not see the straw at the correct place anymore where it actually is in the water.

Figure 2 is a drawing showing how a ray is refracted through a Perspex block. The **normal** is the dotted line that is perpendicular to the boundary, and this has been drawn at the point where the ray hits the Perspex. The angle between the incoming ray and the normal is called the **angle of incidence** ($\angle i$). The angle between the refracted ray and the normal is called the **angle of refraction** ($\angle r$).



▶ figure 2
When light goes through a Perspex block, it is refracted twice.

When rays go from air into Perspex, they are always refracted towards the normal: $\angle r$ is always smaller than $\angle i$.
When rays go from Perspex into air, they are always refracted away from the normal: $\angle r$ is always greater than $\angle i$.



▲ **figure 3**
A ray perpendicular to a boundary does not change direction.

Rays that hit the Perspex at 90° to the Perspex do not change direction (figure 3).

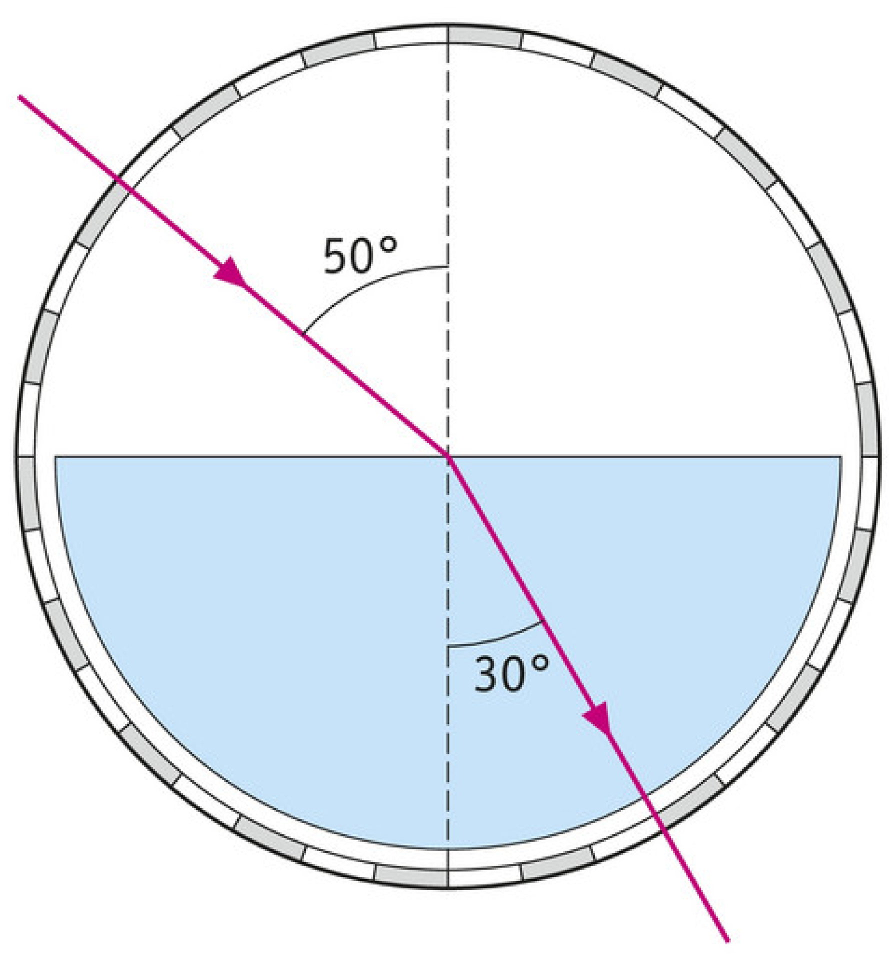
The light is refracted in much the same way at a boundary between glass and air, or water and air.

The relationship between ∠*i* and ∠*r* Experiment 2

Figure 4 shows a drawing of how a ray is refracted by a semicircular Perspex disc. The ray only changes direction when it enters the piece of Perspex. You can read off the angle of incidence and corresponding angle of refraction using the protractor. This is how table 1 was created. The ray is not refracted by the rounded edge of the piece of Perspex, the angle of incidence is always 0° there.

▼ **table 1** the relationship between ∠*i* and ∠*r* on refraction from air to Perspex

∠*i*	∠*r*
10°	7°
20°	13°
30°	20°
40°	25°
50°	30°
60°	35°
70°	39°
80°	41°
90°	42°

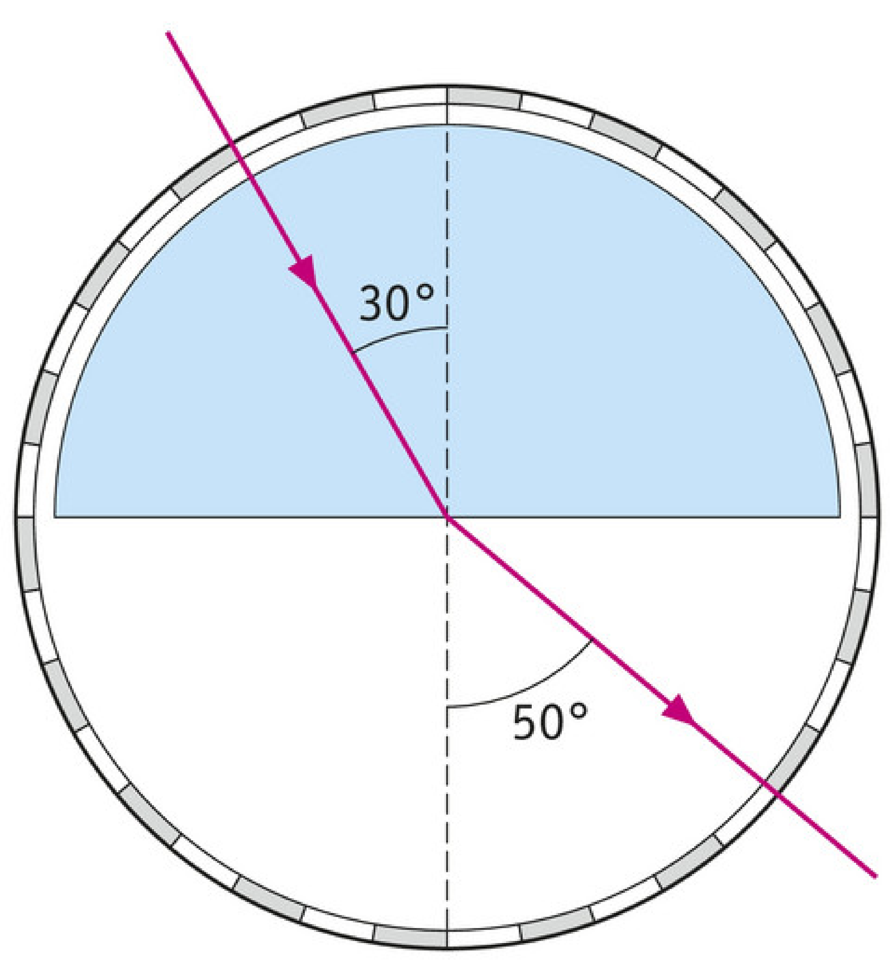


◀ **figure 4**
This is how you measure ∠*i* and ∠*r* for refraction from air to Perspex.

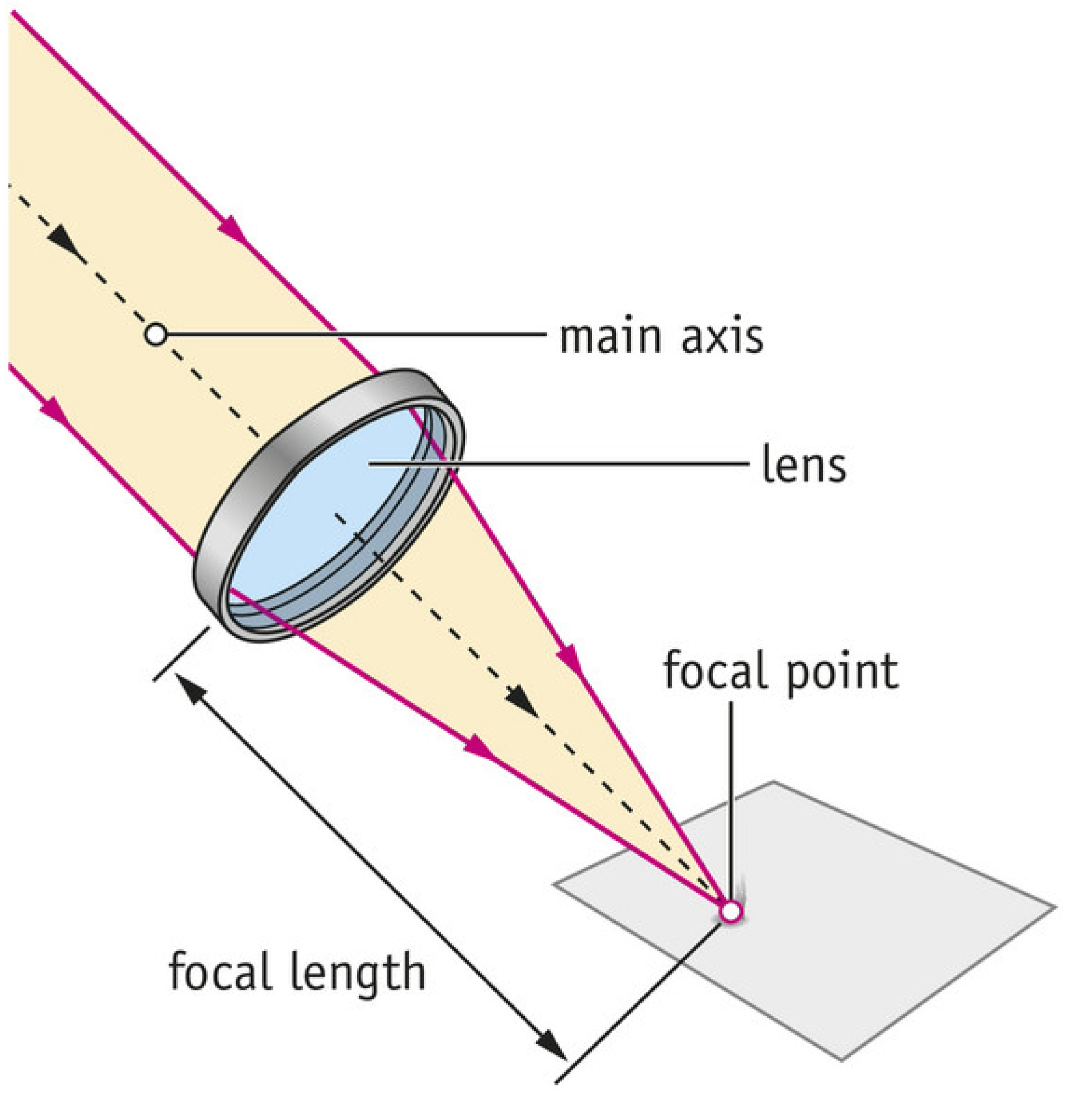
You can also make the ray hit the rounded side of the Perspex disc first (figure 5). In that case, the ray is only refracted when it leaves the Perspex disc. You can measure ∠*i* and ∠*r* again a number of times this way too. The results are shown in table 2. Note that the values of ∠*i* and ∠*r* in table 2 'seem' to have been swapped. In table 1, you have ∠*i* = 30° next to ∠*r* = 50°, but in table 2 ∠*i* = 50° is next to ∠*r* = 30°.

▼ **table 2** the relationship between ∠*i* and ∠*r* for refraction from air to Perspex

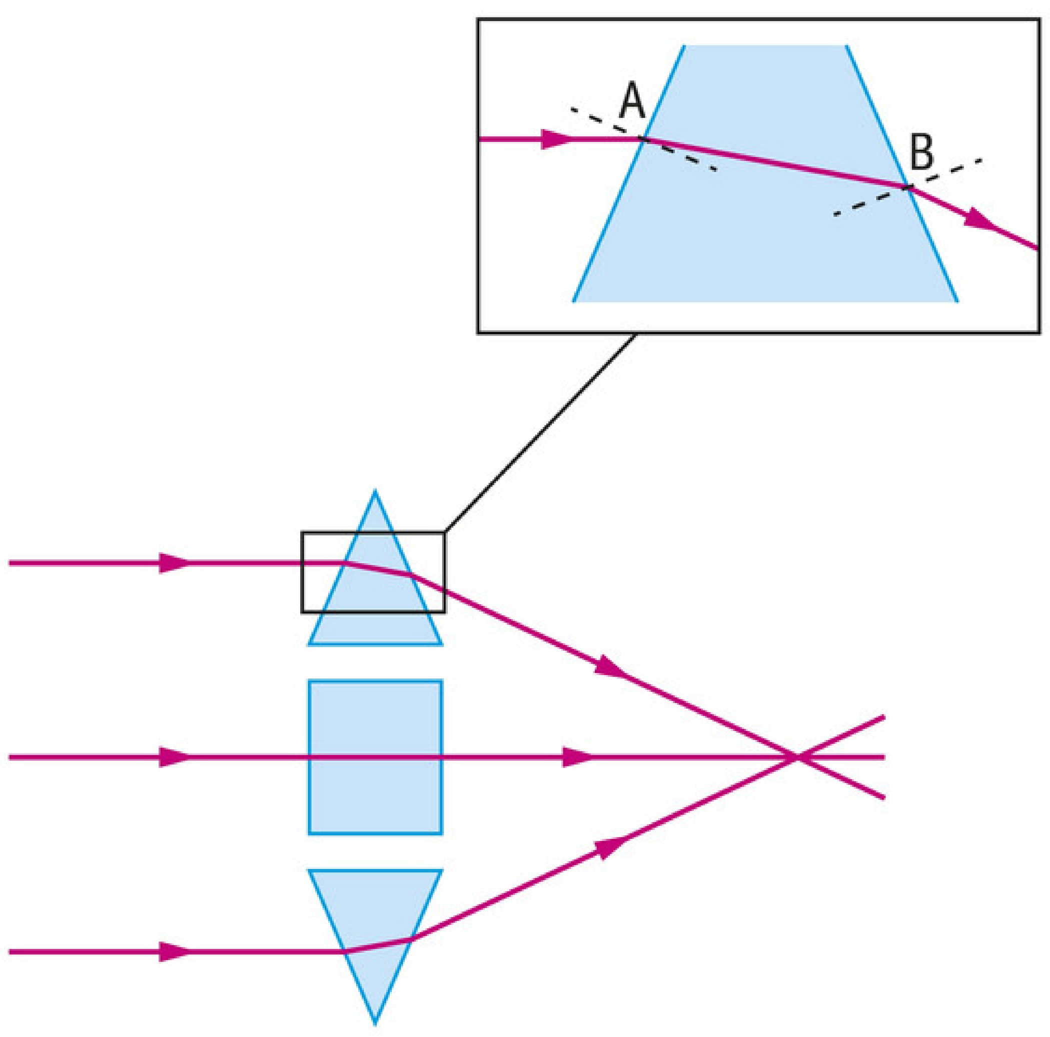
∠*i*	∠*r*
5°	7.5°
10°	15°
15°	23°
20°	30°
25°	40°
30°	50°
35°	60°
40°	74°
42°	90°
45°	--
and so forth	--



◀ **figure 5**
How you measure ∠*i* and ∠*r* for the refraction from Perspex to air.



▲ **figure 6**
How a magnifying glass works.



▲ **figure 7**
refraction through a lens (simplified)

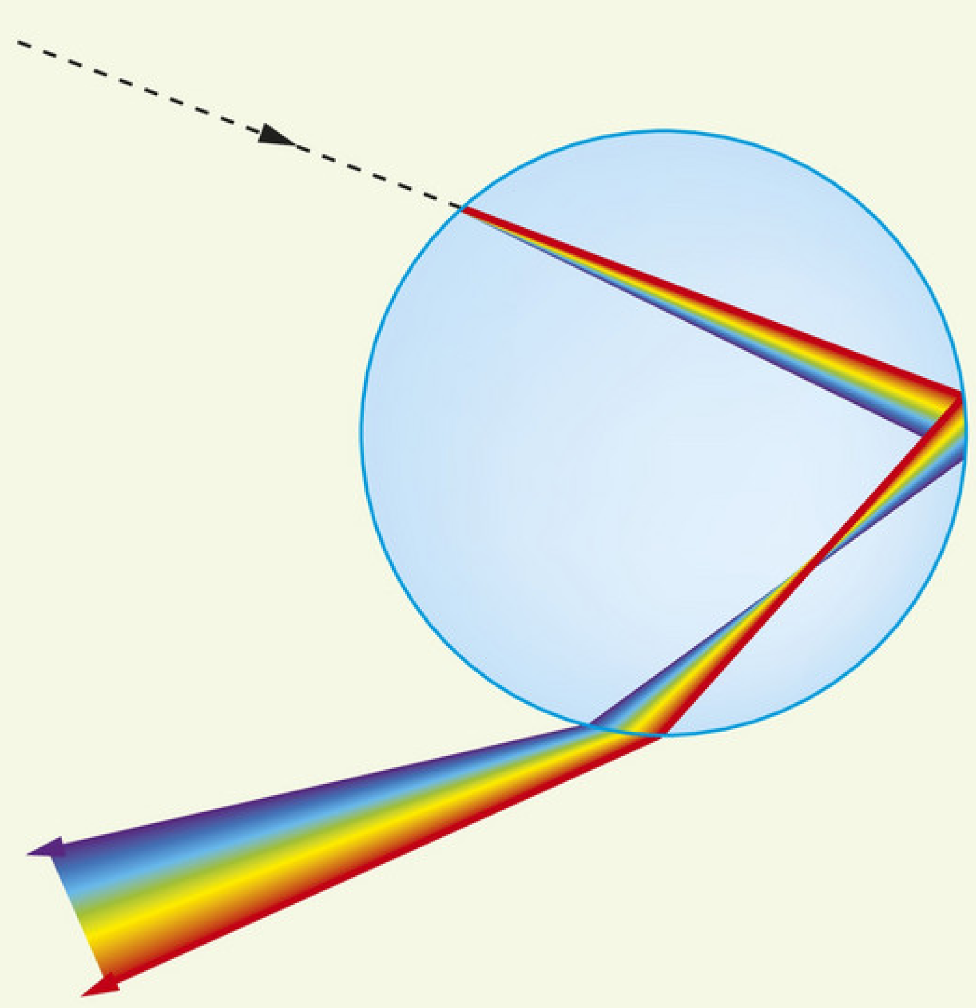
As you can see in table 2, the series of measurements stops at an angle of incidence of 42°. The angle of refraction is then 90°. If you make the angle of incidence greater than 42°, the ray will not be refracted anymore, but fully reflected. In that case, the law of reflection applies: $\angle i = \angle t$, just like a normal mirror.

Refraction by lenses Experiment 3

You can focus a parallel beam of sunlight onto a single point using a magnifying glass. A magnifying glass is a **convex lens** made of glass or plastic that changes the direction of the rays. Figure 6 shows how this works. Before the rays fall onto the lens, they are parallel to its **main axis**, the line that runs through the centre of the lens perpendicular to the lens. After passing the lens, the rays converge and all meet at one point, the **focal point**.

In drawings, the focal point is indicated by the letter F. The distance from the centre of the lens to the focal point F is called the **focal length** f. The focal length is an important property of a lens. The shorter the focal length, the more strongly the lens refracts the light.

Figure 7 will help you to understand how a lens refracts light. This 'lens' consists of two prisms (triangular pieces of glass) and one rectangular block. The prisms refract an incident ray twice: the first time (at A) towards the normal, the second time (at B) away from the normal. As a result, the ray is deflected towards the main axis. The ray that falls on the central part of the 'lens', goes straight through. Somewhat further on, the three rays come together at the focal point.



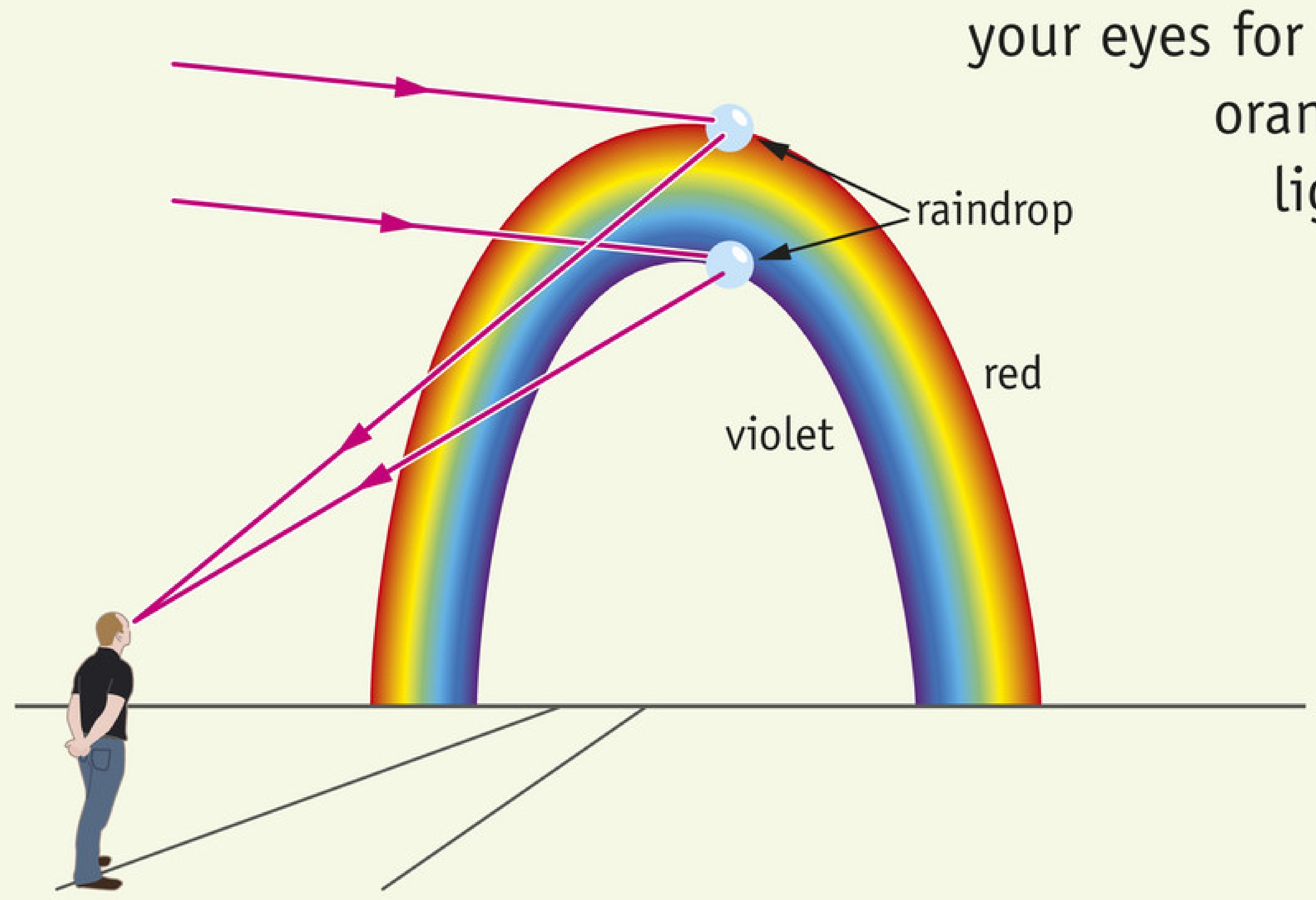
▲ **figure 8**
refraction through a water droplet

Plus Rainbows

When sunlight falls on water droplets, this creates a spectrum of colours: red, orange, yellow, green, blue, indigo and violet. Figure 8 shows you what a water drop does to the incident sunlight. The sunlight is first refracted when it enters the droplet. At the other side of the droplet, it is then reflected. Finally, it is refracted for a second time when it exits the droplet.

As has been shown in figure 8, the refraction of some spectral colours is greater than for others, violet light is refracted most, and red light least. That is why only a single spectral colour reaches your eyes, if you look at such a water droplet at just the right angle. The other spectral colours are refracted too strongly or too weakly and do not reach your eyes.

If you are looking at lots of water droplets at the same time, you can see the full spectrum – a rainbow. Your eyes then receive red light from a ring of water droplets that create precisely the required angle with your eyes for red. Just inside that is a ring of water droplets from which orange light reaches your eyes, and so on through to violet light. The red light comes from the outermost ring of water droplets and the violet light from the innermost ring (figure 9).

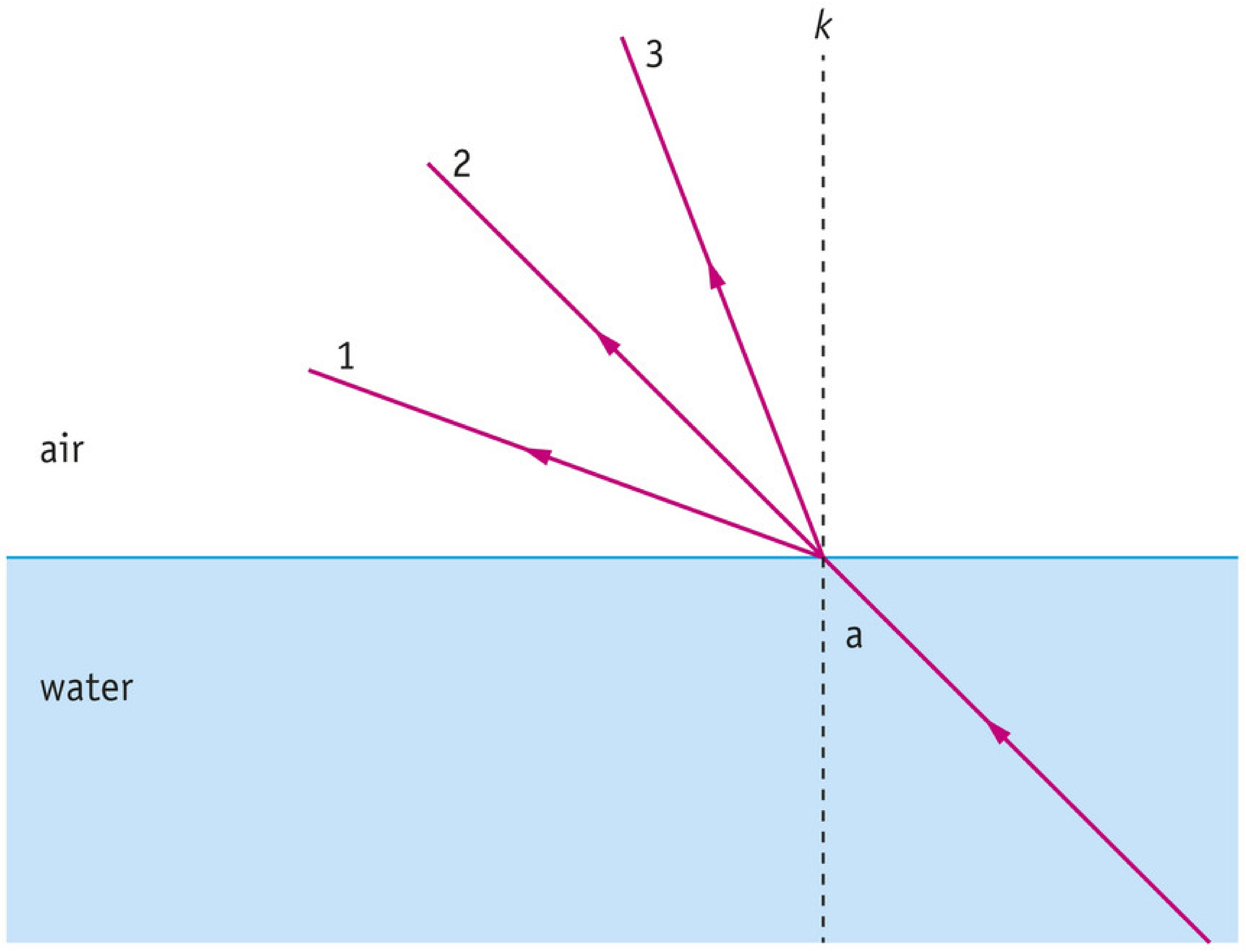


◀ **figure 9**
How a rainbow is created.

Exercises

1 Answer the questions below.
- **a** What is meant by 'the normal at the boundary between the substances'?
- **b** How is a ray refracted when it goes from air into Perspex?
- **c** How is a ray refracted when it goes from Perspex into air?
- **d** How can you focus a parallel beam of sunlight onto a single point?

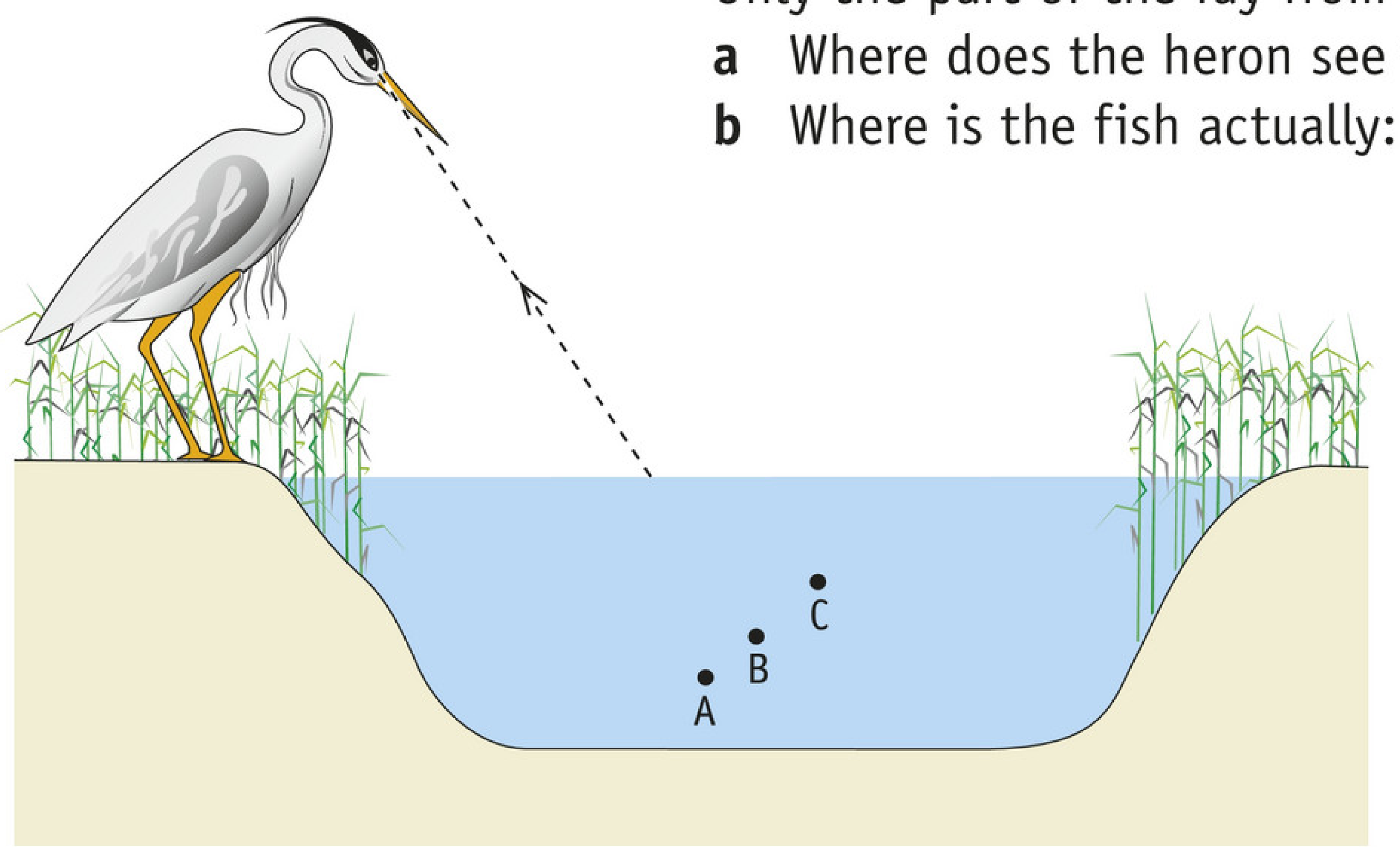
2 Figure 10 shows a ray going from water into air. Only one refracted ray (1, 2 or 3) has been drawn correctly.
- **a** What is the name of the dotted line *k*?
- **b** What is the name of the angle a?
- **c** Explain which ray (1, 2 or 3) has been drawn correctly.



▶ **figure 10**
lines and angles

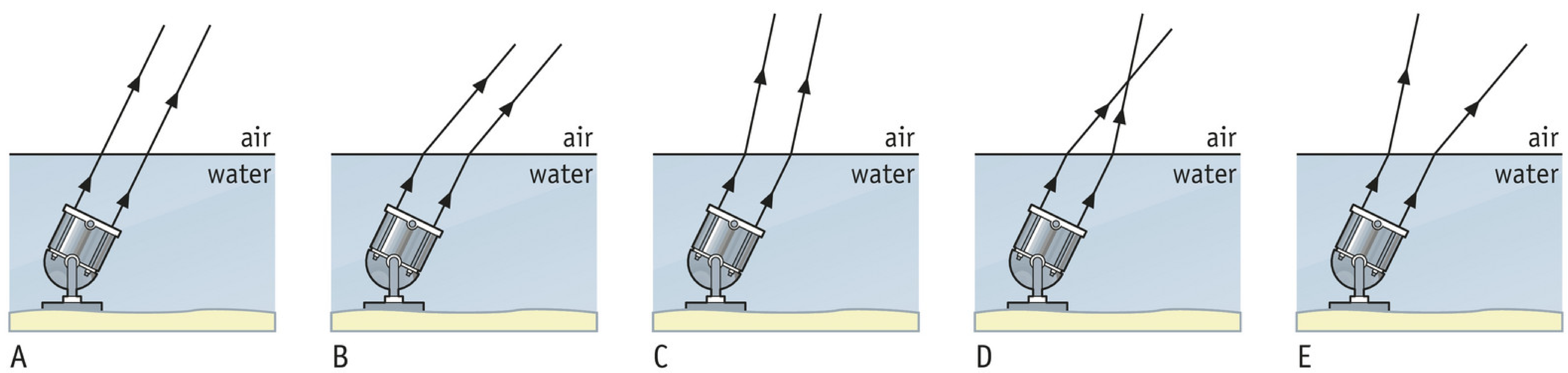
3 You need worksheet 3-1 for this exercise.
You see how two rays hit a pane of glass.
Sketch on the worksheet:
a how ray 1 moves through the pane.
b how ray 2 is refracted when it falls on the pane.
c how ray 2 is refracted when it leaves the pane again.

4 A heron is looking at a fish that is swimming in the water (figure 11).
Only the part of the ray from the fish above the water has been drawn.
a Where does the heron see the fish: at A, B or C?
b Where is the fish actually: at A, B or C?



◀ **figure 11**
knowing where to look

5 A spotlight has been placed under the water.
Which of the five drawings in figure 12 shows the correct path for the ray?

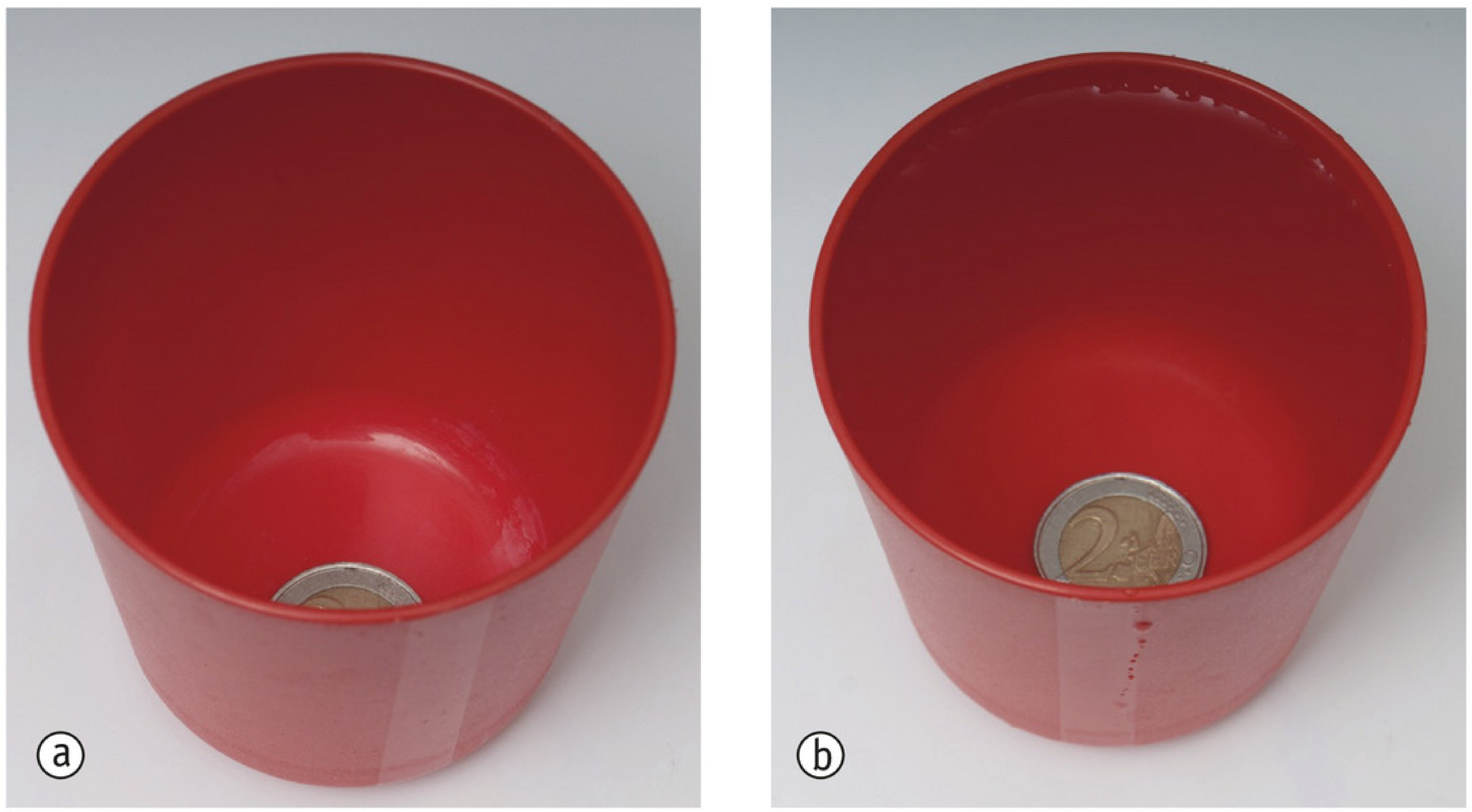


▲ **figure 12**
spotlight in a pond

6 You need worksheet 3-2 for this exercise.
A ray falls on a glass object. The ray passes through the object and exits the object on the other side.
In the drawing on the worksheet, sketch:
a what the object that refracts the light looks like.
b how the ray moves through the object.

7 You need worksheet 3-3 for this exercise.
A parallel beam of light falls on the lens of a magnifying glass.
a Explain why ray 3 does not change direction.
b Sketch on the worksheet how the four rays progress.

***8** Karen puts a coin in a cup. She pushes the cup away from her until she can just not quite see the coin (figure 13a). When she fills the cup with water, the coin can then be seen again (figure 13b).
Explain using a drawing what made it possible for Karen to see the coin again.



▶ **figure 13**
a coin in a cup

***9** At the transition from air to Perspex in figure 2, the ray is refracted towards the normal. How strongly the ray is refracted depends on the refractive index n of the material. The following then applies:

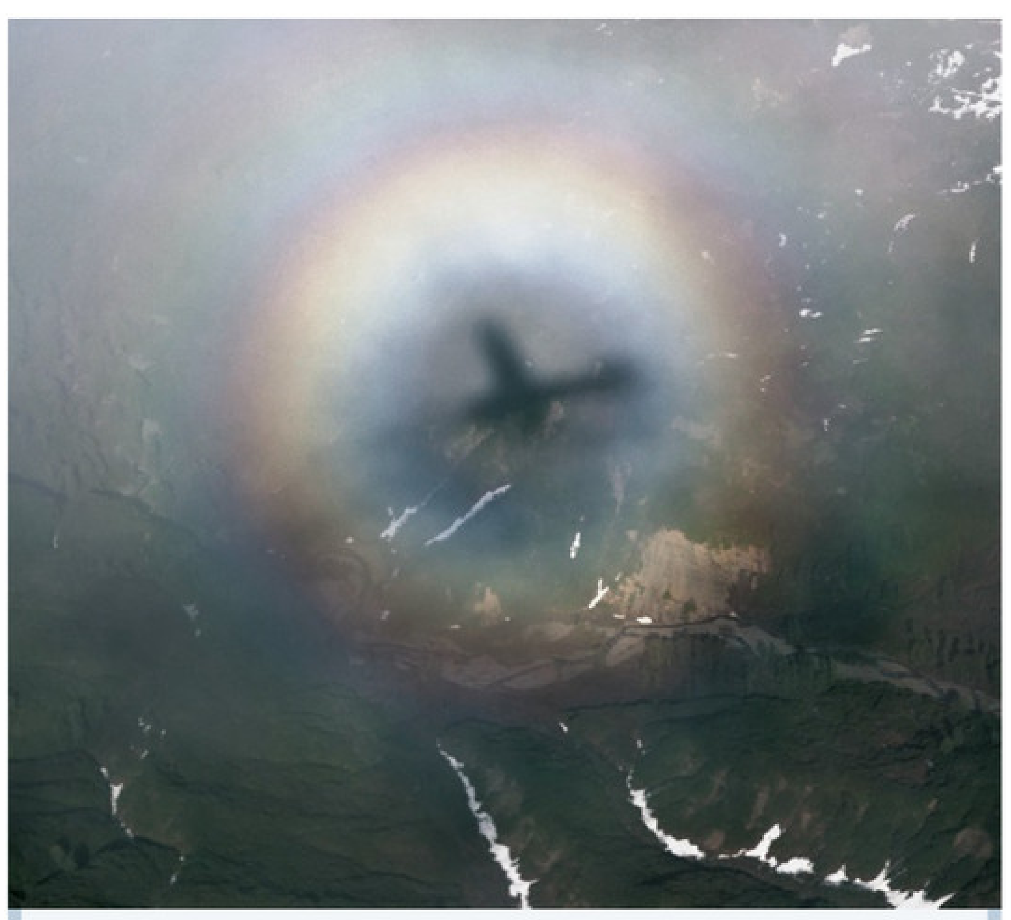
$$\frac{\sin i}{\sin r} = n$$

A ray falls at $\angle i = 45°$ on a diamond ($n = 2.4$).
Calculate the angle of refraction.

Plus Rainbows

10 Figure 14 shows a short fragment from a website about weather phenomena.
- **a** Where was the photograph of the rainbow in figure 14 taken from?
- **b** A complete circular rainbow can never be seen from the ground. Explain why.
- **c** The photo in figure 14 was taken with the Sun at the photographer's back.
  How can you tell this from the photo?

11 You need worksheet 3-4 for this exercise.
The worksheet shows a drawing of a water droplet. You see how a ray travels from A to B through the droplet.
- **a** Sketch how the ray has travelled before it reaches point A in the droplet.
- **b** Sketch how the ray progresses after it has passed point B.



A rainbow is an arc of raindrops that refract the sunlight so that it comes back to your eyes. You can only see the rainbow when the Sun is at your back. If the horizon is not in the way, the rainbow is a full circle.

◀ **figure 14**
a circular rainbow

2 Lenses

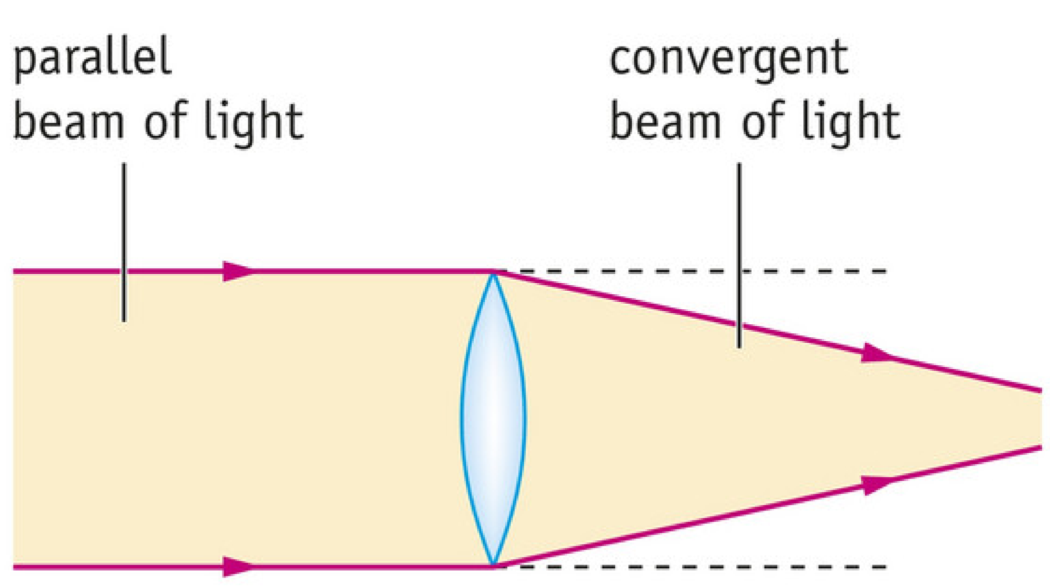
▲ figure 15
A magnifying glass always has a positive lens.

Lenses are found in all kinds of devices: cameras, binoculars, projectors and telephones. The glasses in spectacles are lenses too, as are contact lenses and the 'natural' lenses in your eyes. Lenses let you see the world around you clearly and record images of that world in photos and on film.

Positive and negative lenses

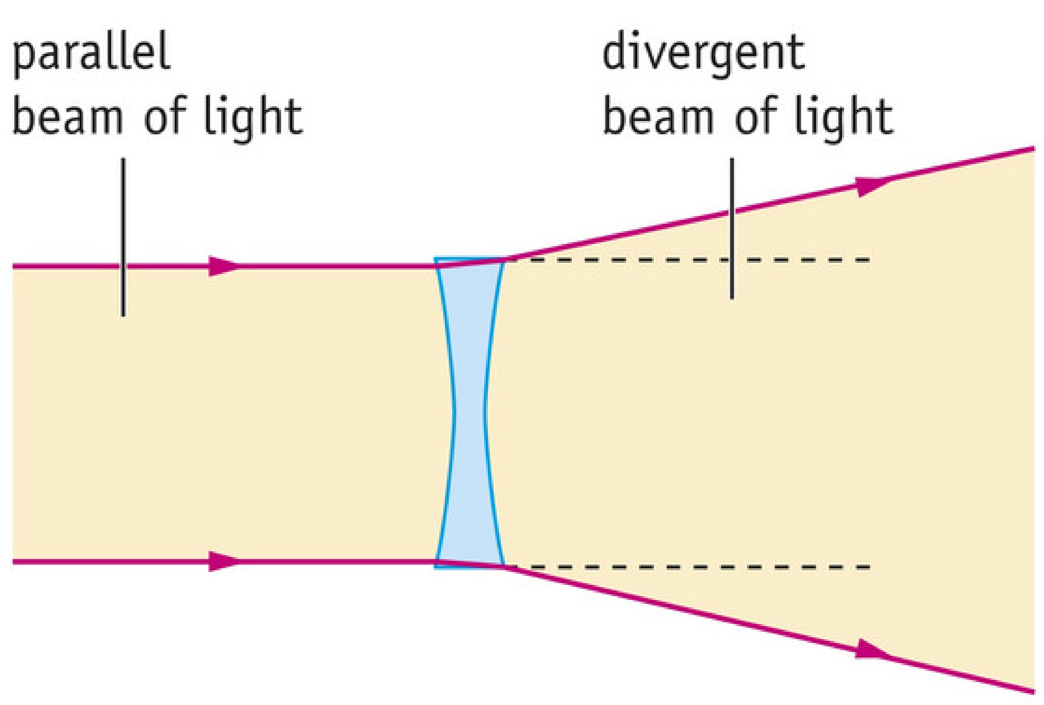
Lenses can be classified in two groups: **positive** and **negative lenses** (figure 15). Positive lenses are thinner at the edges than in the middle. This shape is called a convex lens. Negative lenses are thicker at the edges than in the middle. This shape is called a concave lens.

Positive lenses are **convergent**. This means that rays that fall on the lens are deflected inwards, towards the main axis. You see that when you extend the rays as dotted lines beyond the lens. A parallel beam of sunlight in front of the lens becomes a **convergent** beam after the lens (figure 16). The more convex the lens is, the stronger its converging effect.



▶ figure 16
converging effect

Negative lenses are **divergent**. This means that rays that fall on the lens are deflected outwards, away from the main axis. A parallel beam of sunlight in front of the lens becomes a **divergent** beam after the lens (figure 17). The more concave the lens is, the stronger its diverging effect.



▶ figure 17
diverging effect

▲ **figure 18**
a photo of a black knight (sharp) and a white knight (blurred)

Creating images using a lens Experiment 4

You can use a positive lens to create an image of an object on a screen. You do this when you take a photograph, for example. A lens in the camera produces a small image of the view in front of the lens on a light-sensitive image sensor chip (CCD or CMOS). A computer in the camera records that image pixel by pixel in a file. After that, the file is stored on a memory card. This lets you view, upload or print the image later on.

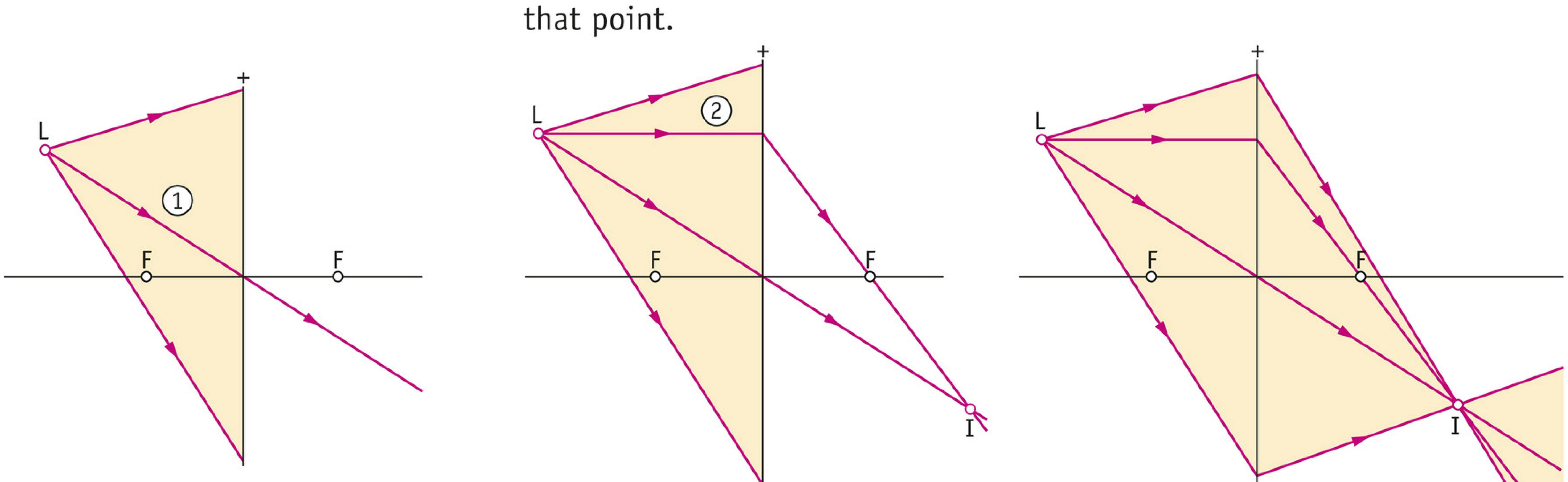
When you take a photograph, light from the object falls on the lens. This could be reflected light or light that is emitted by the object itself. The lens makes sure that all the light from any one point on the object comes together at a single point again. This point is called the **image point** I of the object point O: in computer terms, a **pixel**. One photograph consists of millions of pixels.

If the image sensor is at the right distance from the lens, the photo will be sharp (figure 18). A photo consists of pixels that do not overlap each other. If the sensor chip is not at the correct distance, the photo will be blurred. The image points in the photo have then become small circles that overlap each other partially (over several pixels), making the boundaries between the coloured fields become vague.

Construction rays

A scale drawing lets you find out how an image is created behind the lens. This is called **constructing** the image. Two special rays are used for this. You know beforehand exactly how these **construction rays** will travel:
- Construction ray 1 goes through the centre of the lens and does not change direction.
- Construction ray 2 runs parallel to the main axis in front of the lens. Beyond the lens, this ray will go through the focal point F of the lens.

Figure 19 shows you how a beam of light from a bulb L falls on a lens. You can find the image point I by drawing two construction rays. All rays that fall on the lens from L will be refracted towards that point. You can therefore then draw how other rays from the bulb are refracted towards that point.



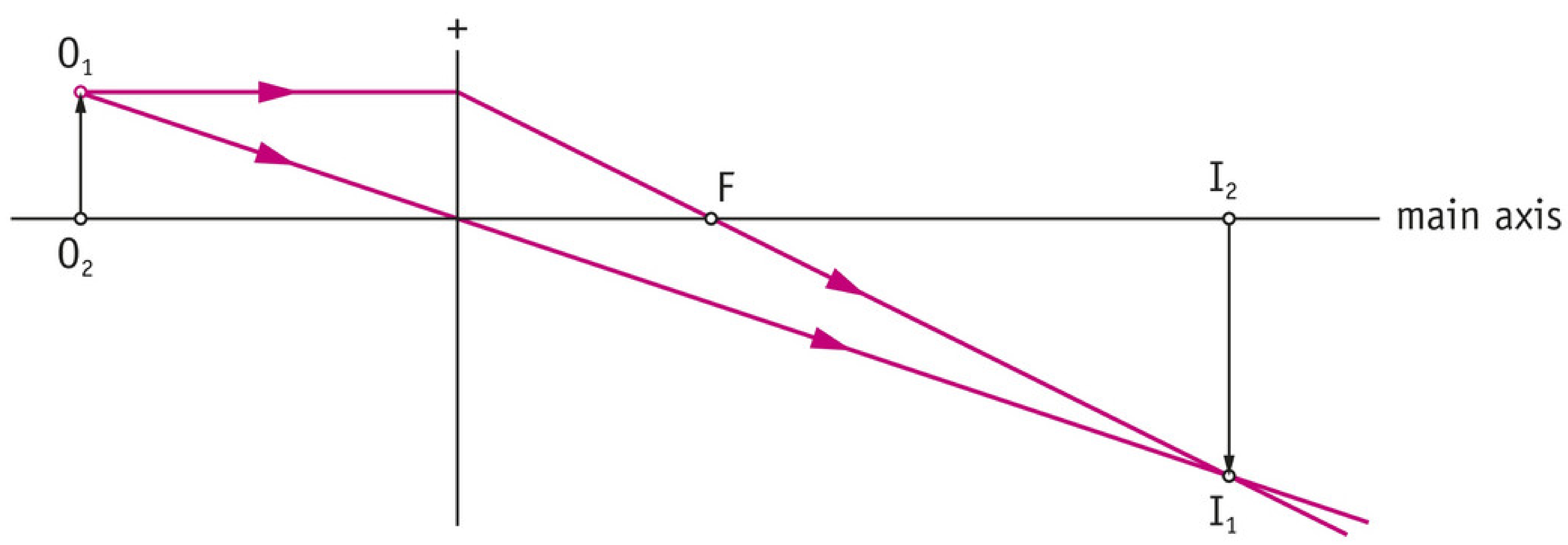
▲ **figure 19**
How to construct the image of a bulb.

Drawing the location of the image

Figure 20 is a sketch showing how the image of an object can be constructed.

1 Draw the lens and the main axis. Draw the focal point at the right distance from the lens and put a letter F next to it.
2 Draw the object as an arrow O_1O_2 at the right distance in front of the lens. O_2 is on the main axis and O_1 is above it.
3 Draw the two construction rays from O_1. Draw the image point I_1 where the rays come together.
4 Draw the image as an arrow I_1I_2. I_2 is on the main axis and I_1 is below it. The image is therefore upside down (compared to the object).

The object is sometimes bigger than the lens. In that case, you may extend the lens upward and downward in the drawing. After that, you can use the construction rays again to find the location of the image.



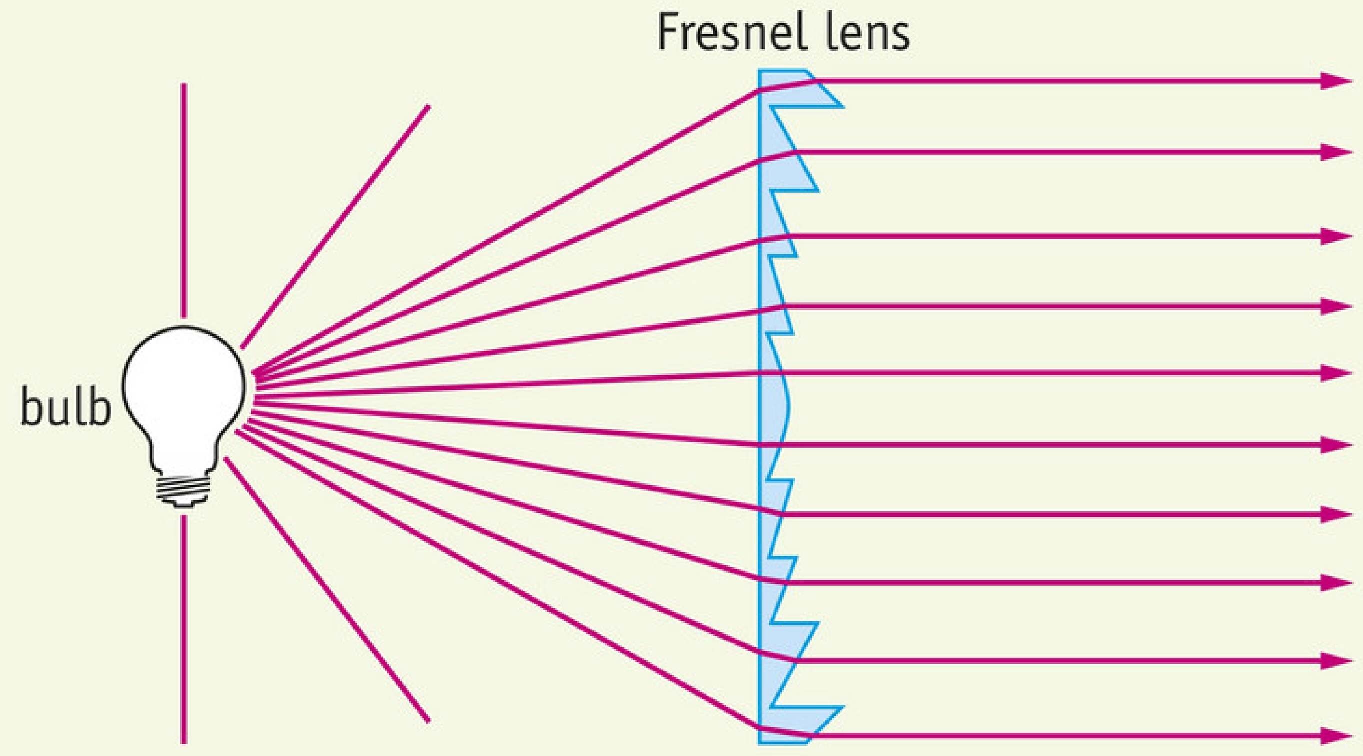
▶ figure 20
How to draw the location of the image.

Plus Fresnel lenses

A lighthouse uses a large positive lens to make the light from a big bright bulb into a beam. A lens like that could not be ground from a single piece of glass because it would be much too heavy then. Instead of that, a lens is used that is made up of rings of glass (figure 21). Each ring is a piece of a positive lens. A lens made up of rings this way is called a Fresnel lens.

▲ figure 21
a Fresnel lens in a lighthouse

Fresnel lenses refract light almost like a normal lens. You cannot make nice pictures with them, but they are very suitable for bundling light into beams (figure 22). They are widely used for that purpose because they are much thinner and lighter than normal lenses. They are also used in the rear lights of cars and as condenser lenses in video projectors, for example.



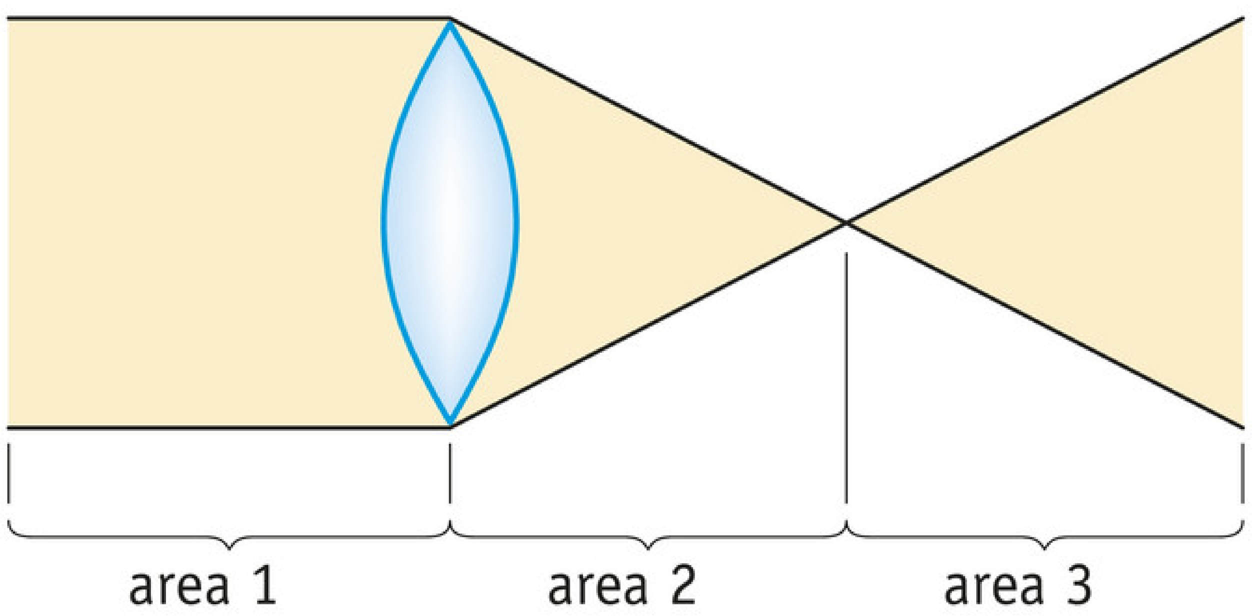
▶ figure 22
How a Fresnel lens refracts light.

Exercises

12 Answer the questions below.
- **a** How can you tell whether a lens (such as a lens in a pair of spectacles) is positive or negative?
- **b** How is a parallel beam of sunlight refracted by a positive lens?
- **c** What does the lens in your camera do with the light that comes from any single point of the object?
- **d** What has gone wrong when you take a photo but get a blurred image?

13 There are three types of light beams.
- **a** Sketch each type of beam in your workbook.
- **b** Write down next to it what name is given to this type of beam.

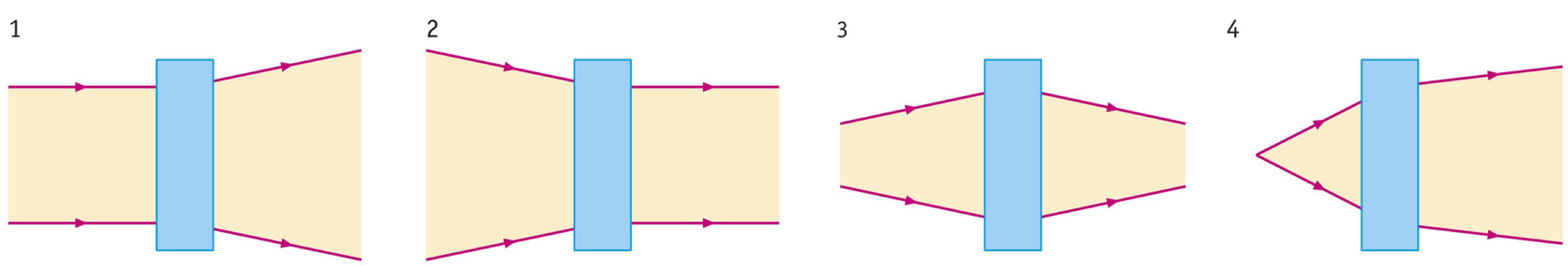
14 Joyce wants to light a piece of paper using a spectacle lens. She holds the spectacle lens in the sunlight.
- **a** What will Joyce see:
  - if the spectacle lens is positive?
  - if the spectacle lens is negative?
- **b** Does she therefore need a positive or negative spectacle lens?
- **c** What must Joyce do to set the paper on fire?



▲ **figure 23**
a beam of light passing through a lens

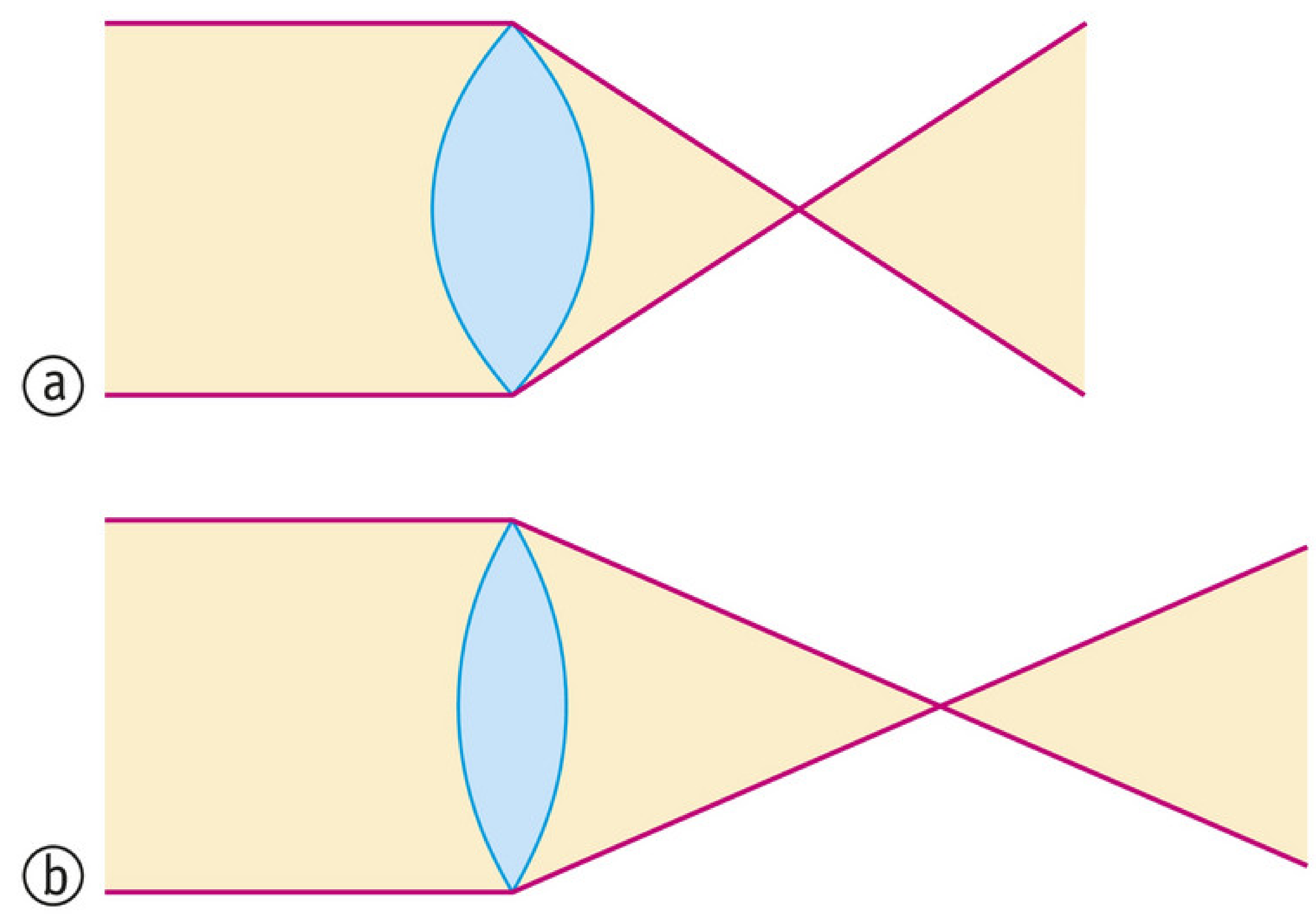
15 Assume that the light in figure 23 is coming from the left.
- **a** What type of light beam is there:
  - in area 1?
  - in area 2?
  - in area 3?
- **b** Answer the same questions once again, but now assuming that the light is coming from the right.

16 In each of the four boxes in the drawing in figure 24, there is a lens. For each box, say:
- **a** whether it has a positive or negative lens in it.
- **b** how you can tell what type of lens it is.



▲ **figure 24**
What kind of lens is in each box?

17 Figure 25 shows cross-sections of two lenses.
- **a** Which of the two lenses is stronger?
- **b** What is the focal length of each lens?



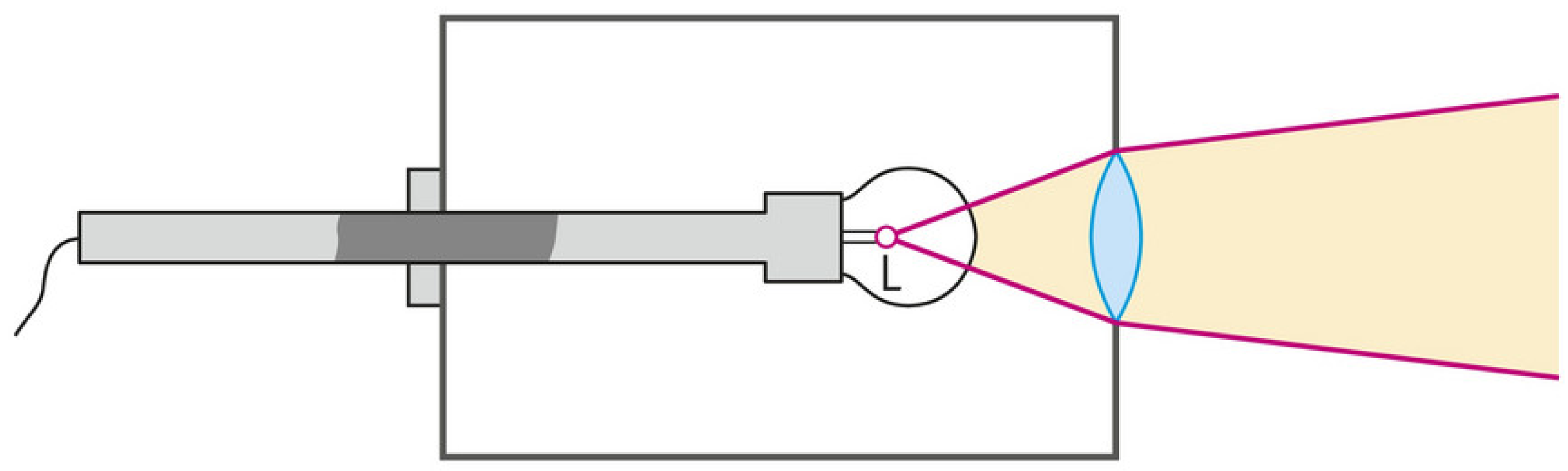
▶ **figure 25**
strong and stronger

18 You need worksheet 3-5 for this exercise.
There is a bulb in front of a lens. Four rays hit the lens.
- **a** Which two rays on the worksheet are construction rays?
- **b** Sketch how the construction rays continue after the lens.
- **c** Sketch how the other two rays are refracted.

19 You need worksheet 3-6 for this exercise.
Abdul has inserted a slide at the front of a light box. There is an arrow on the slide. Abdul moves the light box closer and closer towards a positive lens.
- **a** Construct (i.e. draw) the position of the image I_1I_2 in each of the three drawings.
- **b** How does the image change as the slide is moved closer and closer towards the lens?

20 You need worksheet 3-7 for this exercise.
From an object O_1O_2, two rays fall on a positive lens.
Sketch on the worksheet how the rays are refracted by the lens.

***21** Libby is working with a light box for a physics practical (figure 26).
The box has a positive lens with a focal length of 8.0 cm.
- **a** What kind of light beam comes from the light box?
- **b** Libby wants a parallel beam to come from the light box. She therefore moves the bulb.
  Explain whether she has to move the bulb to the left or to the right.
- **c** To what distance does she have to move the bulb from the lens?



▶ **figure 26**
a light box for a physics experiment

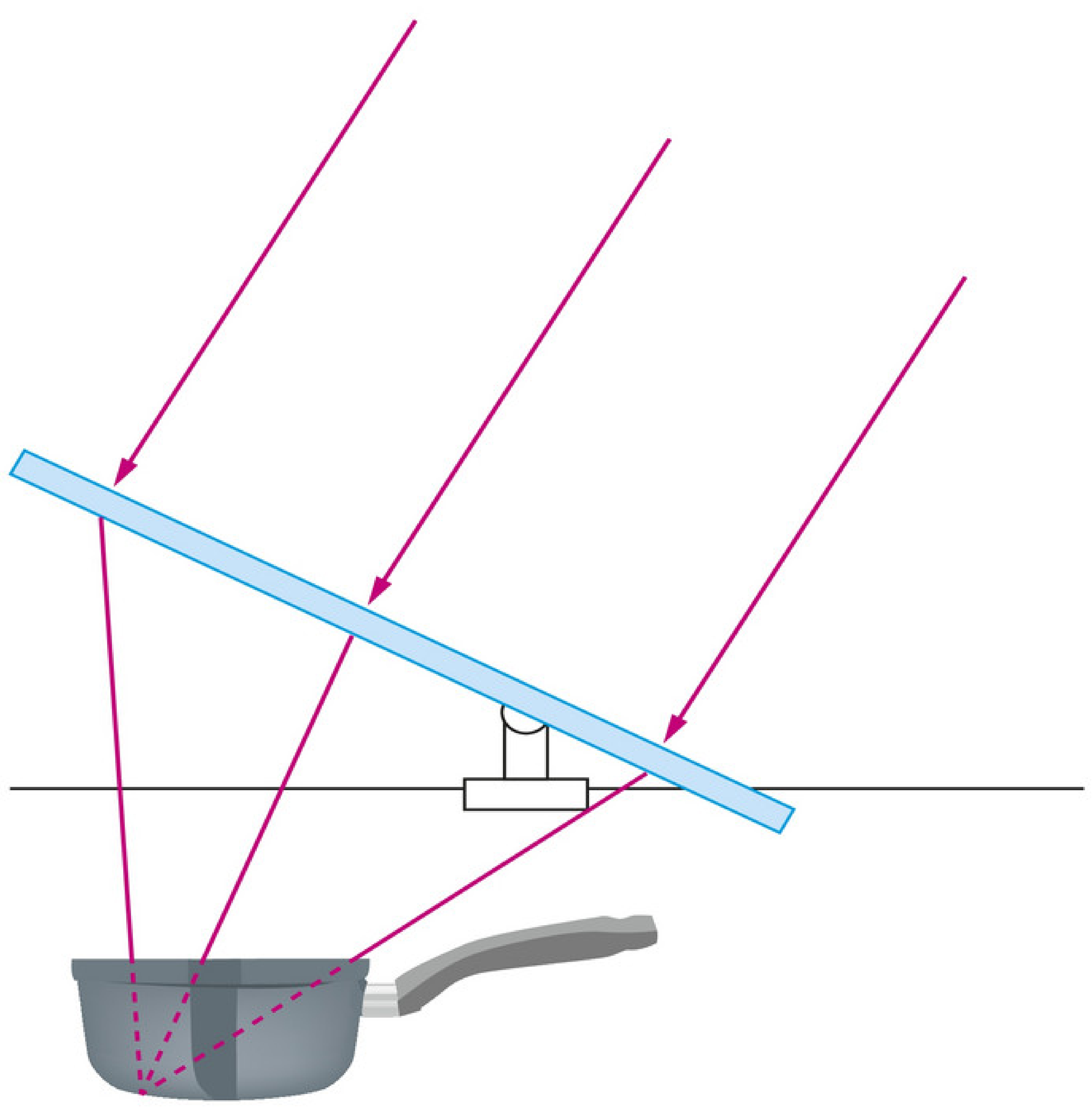
22 You create an image of a candle flame on a wall using a large lens. After that, you replace the large lens with a small lens that has the same focal length.

- **a** Does this change the position of the image? If so, how?
- **b** Does this change the size of the image? If so, how?
- **c** Does this change how bright the image is? If so, how?

Plus Fresnel lenses

23 Fresnel lenses can also be used to heat water using sunlight (figure 27).

- **a** Explain whether the Fresnel lens in figure 27 is a positive or a negative lens.
- **b** You can use a large Fresnel lens to heat water more quickly than using a magnifying glass (a glass that can create a fire). Explain why.



▶ **figure 27**
boiling water using a large Fresnel lens

24 Figure 28 shows a photograph of what you see when you look through a positive and a negative Fresnel lens. Explain which of the two lenses is the positive lens.

▶ **figure 28**
two different Fresnel lenses

3 Cameras and projectors

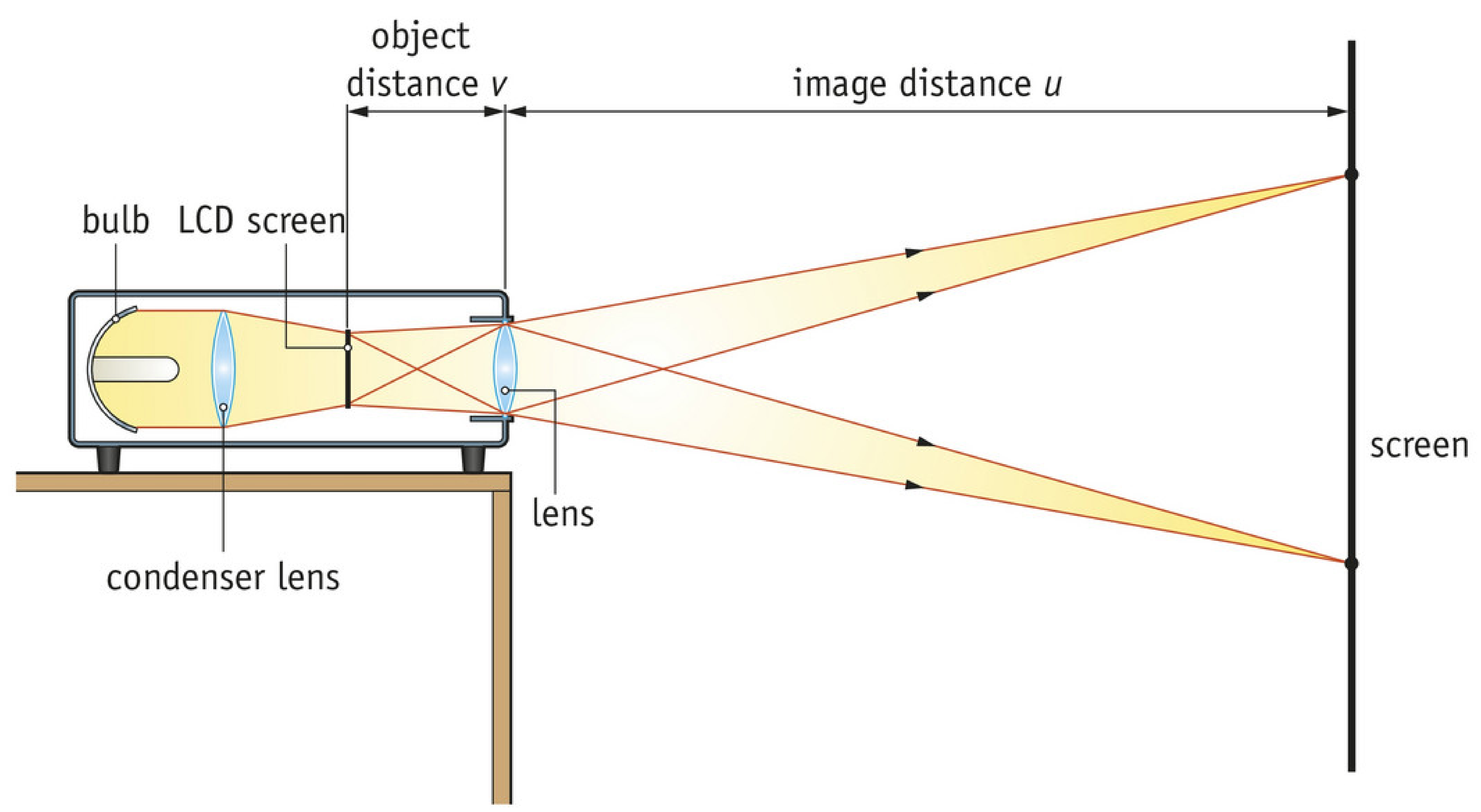
You can record images using a camera. You can use a projector to magnify the recorded images and project them. Focusing is important for both devices to make sure that details are not lost.

Focusing

The way a projector works is similar to a camera. They both have a positive lens that displays an object on a screen. For a camera, the object is the scene that you are photographing. For an LCD projector, that object is an LCD (a *liquid crystal display*) showing a photograph or a video recording. (There are also types of projectors that do not use an LCD but instead have a different 'object'. That makes no difference for the way the projection works.)

Before you can take a good photo, you have to focus the image. In a camera, this is done by adjusting the distance between the lens and the image sensor. Modern cameras do this automatically: a small motor moves the lens forward or backward until the image is razor-sharp. Some cameras can be focused manually too. This can be useful if you want to take a special or unusual photograph.

The images from a projector have to be focused too. The screen has to be placed at the distance where the rays from one point of the LCD screen come together in a single point again. This makes sure that each pixel of the LCD screen is displayed as a pixel (figure 29). In practice, though, you do not move the screen. Instead, you change the distance between the LCD screen and the lens until the image on the screen is sharp.



▶ **figure 29**
the light beam passing through a projector

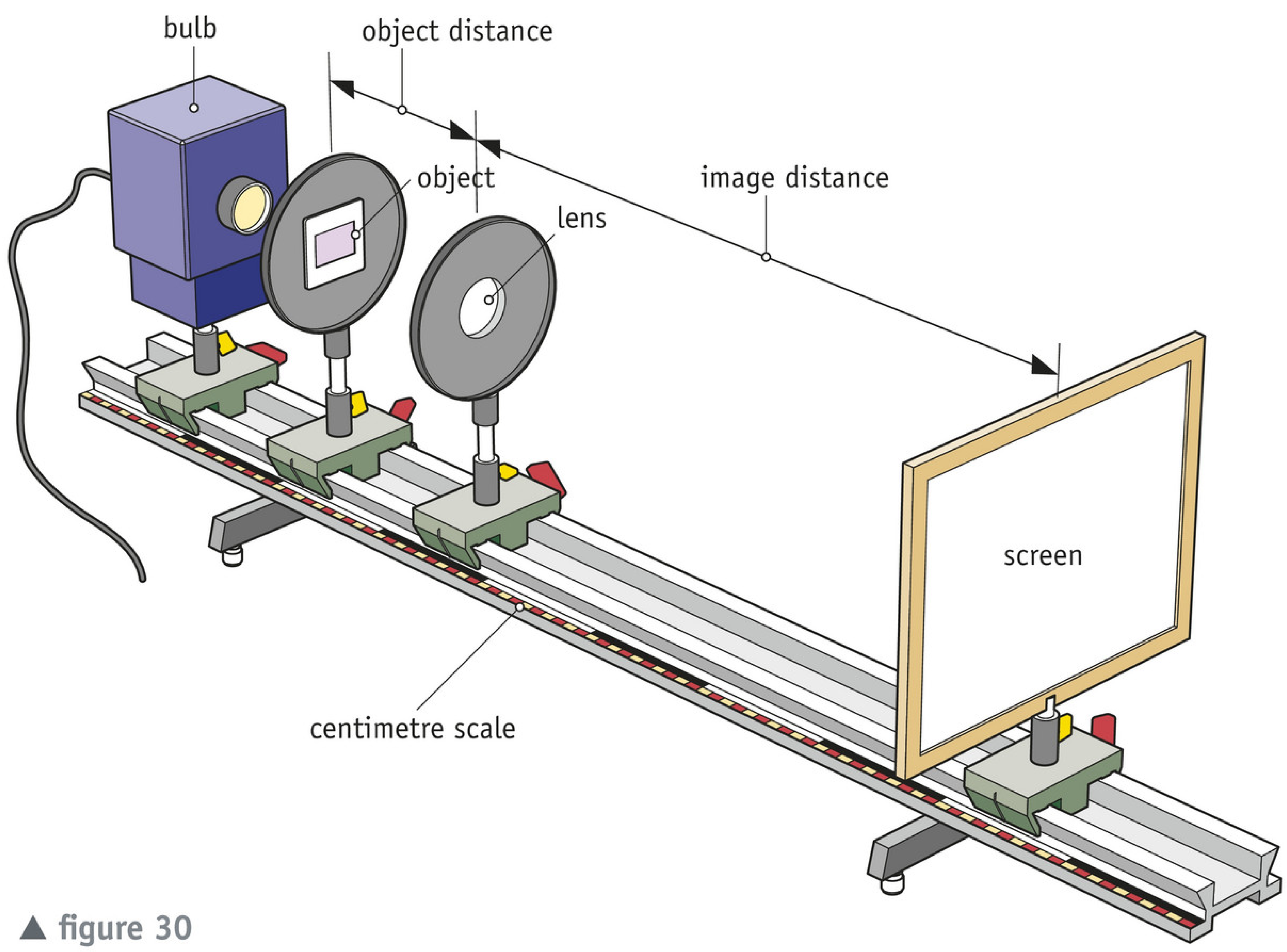
The lens equation Experiment 5

When you focus a camera or a projector, two distances are important:
1 the distance between the lens and the object, this is the **object distance** *u*;
2 the distance between the lens and the sharp image, this is the **image distance** *v*.

For every object distance, there is precisely one image distance. You can only have a sharp image at that distance.

The relationship between *u*, *v* and *f* can be investigated using the setup in figure 30. The lens creates a sharp image of the object on the screen. Experiments such as this show that, for *u*, *v* and *f*, the following **lens equation** holds:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$



▲ **figure 30**
the setup for deriving the lens equation

Worked example 1
Giles wants to play a movie on a video projector. He is using a white wall as a screen. The projection lens of the projector has a focal length of 15 cm. The distance between the lens and the wall is 435 cm. Calculate how far Giles must place the LCD screen from the projection lens.

data f = 15.0 cm
v = 435 cm

required u = ?

working
1 Write down the equation: $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

2 Complete the equation: $\frac{1}{15.0} = \frac{1}{u} + \frac{1}{435}$

3 Take it to the other side: $\frac{1}{u} = \frac{1}{15.0} - \frac{1}{435}$

4 Calculate the fractions: $\frac{1}{u} = 0.0689...$

5 Invert: $u = 1 \div 0.0689... = 14.5$ cm

▲ **figure 31**
a greatly magnified image

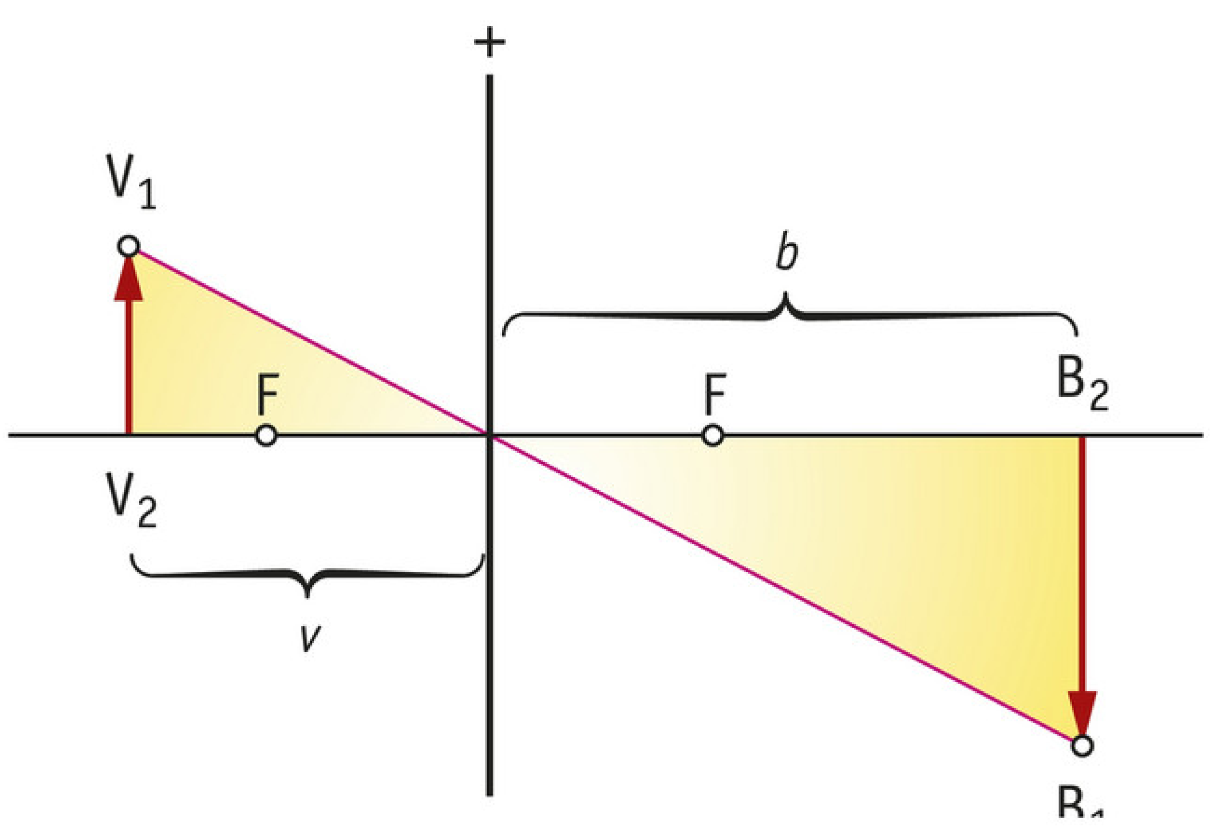
Calculating the magnification

The image is mostly not the same size as the object. Images can be greatly magnified or greatly reduced, or anything in between (figure 31). If you know the dimensions of the object and the image, you can calculate the **magnification** M:

$$M = \frac{\text{height of the image}}{\text{height of the object}}$$

If the image is larger than the object, M is greater than 1. This is the case for a projector, for example: the image on the projection screen is much larger than the LCD in the projector. If the LCD is 3.0 cm wide and the image of the LCD projected on the screen is 3.0 m wide, then the magnification M is 100.

If you take a photograph using an ordinary camera, the image on the image sensor will be smaller than the object. In that case, M is less than 1. If the object is 1.80 m tall and the image of the object is 1.8 cm high, then the magnification M is 0.01. As you can see, you can still use the word 'magnification' now, even though the image is reduced.



▲ **figure 32**
This drawing lets you derive the formula for the magnification.

Figure 32 lets you conclude the following about the magnification:

$$M = \frac{v}{u}$$

This formula is often used together with the lens equation.

Worked example 2
Giles is playing a movie on a video projector. For the data, see worked example 1.
Calculate the magnification.

data u = 14.5 cm
v = 435 cm

required M = ?

working $M = \dfrac{v}{u} = \dfrac{435}{14.5} = 30.0\times$

Plus The refracting telescope

A telescope magnifies and lets you see very distant objects. The instrument was invented more than 400 years ago in Middelburg (in the Netherlands). This 'Dutch viewer' consisted of a tube with two lenses in it. A few decades later on, the reflecting telescope was invented, which used curved mirrors instead.

A refracting telescope has at least two lenses. The lens that is closest to the object is called the **objective lens**. The **eyepiece lens**, the second lens, is closest to the observer. The objective lens is always large to make sure it can collect a lot of light. This is necessary to make sure that very distant objects that are faint can still be seen clearly.

◀ **figure 33**
a tourist looking at the landscape using a telescope

Objects look bigger when you view them through a telescope (instead of with the naked eye). How much an object is magnified can be seen from the magnification of the telescope. A telescope with a magnification of 20 makes an object appear 20× larger. You can calculate the magnification M for a telescope using the formula:

$$M = \frac{f_{obj}}{f_e}$$

As you can see, the magnification depends on the focal lengths of the two lenses.

Exercises

25 Answer the questions below.

- **a** How is the picture in a camera focused when you take a photograph?
- **b** What is the lens equation? What do the three letters v, f and u stand for?
- **c** How can you calculate the magnification, if you know what v and u are?
- **d** What can you tell about the image if the magnification M is less than 1?

26 You need worksheet 3-8 for this exercise.
The light from a bulb falls on a positive lens.

- **a** Put a letter B at the point where the bulb is.
- **b** Put a letter I at the point where the image of the bulb is.
- **c** Draw the main axis of the lens.
- **d** Measure and write down the object distance.
- **e** Measure and write down the image distance.

27 Michael uses a positive lens (f = 8 cm) to display a bulb on the screen. To do this, he moves the bulb closer and closer towards the lens. Calculate where Michael has to put the screen in order to get a sharp picture:

- **a** if the bulb is 18 cm behind the lens.
- **b** if the bulb is 15 cm behind the lens.
- **c** if the bulb is 12 cm behind the lens.
- **d** if the bulb is 9 cm behind the lens.

28 Continuation of exercise 27.
Michael then places the bulb 8 cm behind the lens, at the focal point.

- **a** What goes wrong when you try to calculate the image distance?
- **b** What kind of light beam is created behind the lens if $u = f$?

29 Karen loves photography. Figure 34 shows two of her photos. The object distance is shown for each photo. The lens in her camera has a focal length of 50 mm.
Calculate the corresponding image distance for each value of u. Always show all the steps in your calculation.

u = 100 m

u = 20 cm

▶ **figure 34**
taking photos

30 You need worksheet 3-9 for this exercise.
A lens creates a sharp image of an object O_1O_2.

- **a** Construct the image of O_1.
- **b** Draw the image of O_2.
- **c** State where you have to put the projection screen.
- **d** Calculate the magnification.

31 Desiree is 1.6 m tall. She is standing upright at a distance of 4.0 m in front of a security camera. Desiree's image on the sensor chip of the camera is 8.0 mm high.

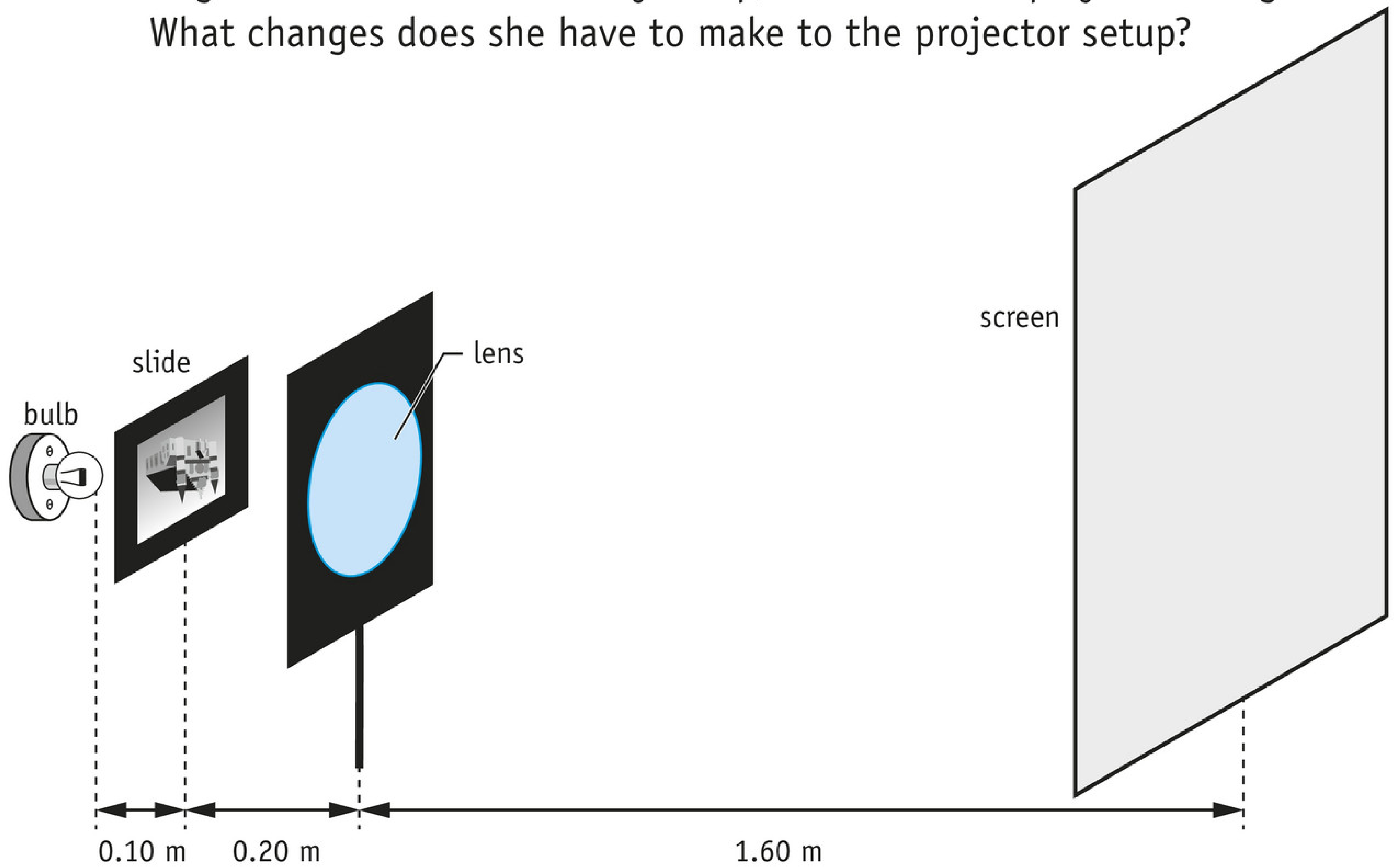
- **a** Calculate the magnification.
- **b** Calculate the image distance.
- **c** Calculate the focal length of the camera lens.

32 Draw a main axis and add a mark in the middle of it that represents a positive lens with a focal length of 3 cm. Draw an arrow 2 cm perpendicular to the main axis, 5 cm from the lens.

- **a** Construct the image of the arrow.
- **b** Check using a calculation whether the image in your drawing is at the right point.
- **c** Check using a calculation whether the magnification you get in your drawing matches the theoretical magnification.

33 Angie has set up the experiment shown in figure 35. In the situation in the drawing, the slide is displayed very sharply on the screen.

- **a** Calculate the focal length of the lens using the data from figure 35.
- **b** The slide is 2.5 cm wide. Calculate the width of the image of the slide on the screen.
- **c** Angie wants the slide to stay sharp, but for the display to be larger. What changes does she have to make to the projector setup?



▶ **figure 35**
displaying a slide

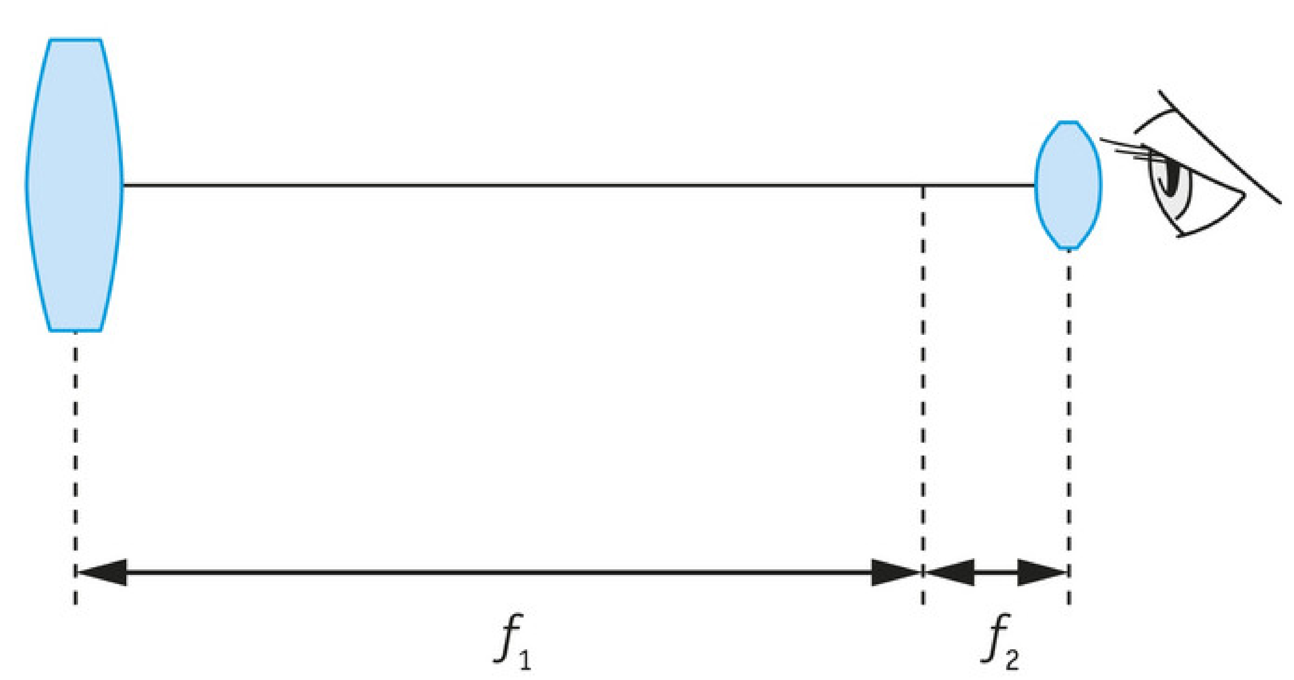
***34** Hannah has a camera with a lens that has a focal length of 20 mm. She takes a picture of a church tower at a distance of 50 m from the lens. Hannah claims that in cases like this you can calculate the magnification using the formula $M = f/u$, because u is much larger than f.
Show that Hannah is right.

Plus The refracting telescope

35 Everett and Carol are building a simple telescope. They use two positive lenses, one with $f = 4$ cm and the other with $f = 20$ cm.

- **a** Explain which lens they have to use as the objective lens.
- **b** Calculate the magnification of their telescope.

36 Continuation of exercise 35.
On a website about telescopes, Everett and Carol read what the distance between the objective lens and the eyepiece lens should be (figure 36).
Calculate the minimum length of the telescope tube.



The positive lenses in a telescope are placed so that the focal points of the objective lens and the eyepiece lens are at exactly the same point.

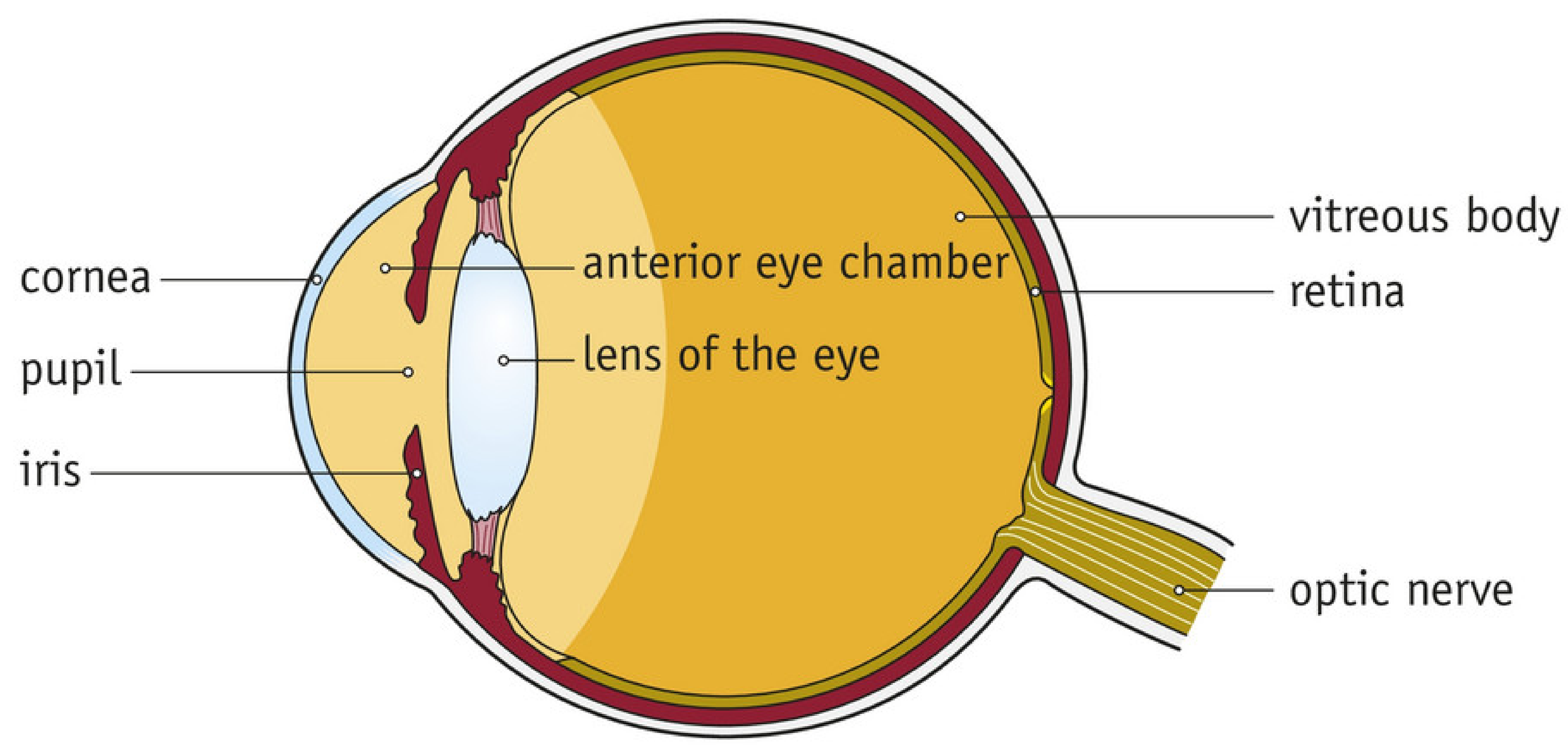
▶ **figure 36**
the distance between the objective and the eyepiece in a telescope

4 Eyes and spectacles

In order to see clearly, there must be enough light. It will create a picture of the world around you on your retina. If you have good eyes, you can focus this image with no problem. But if you cannot, you will need glasses or contacts.

The structure of your eyes

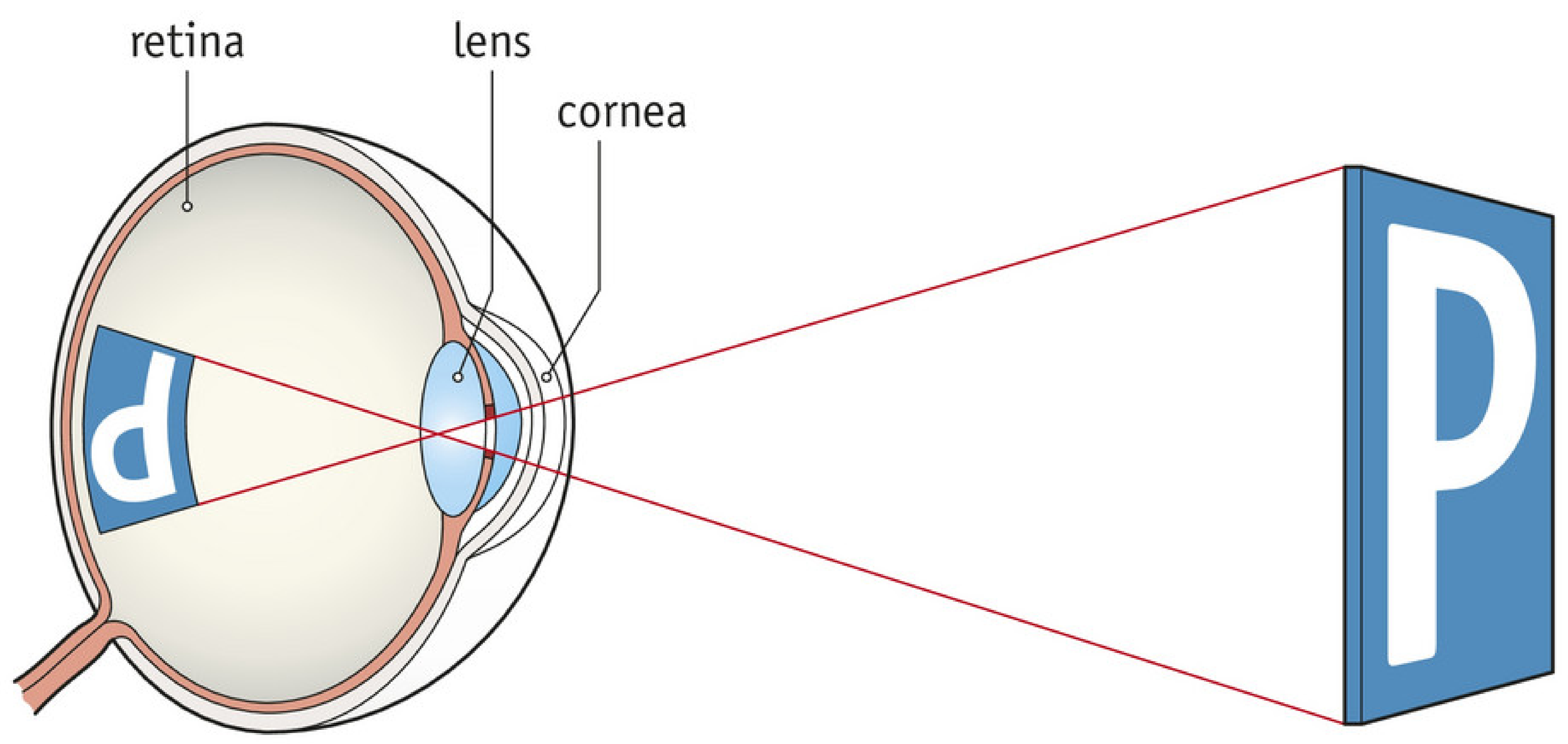
You can see the things around you because they reflect light towards your eyes (or because they emit light themselves). After that, the light passes through the transparent parts of your eye: it goes through the cornea, the lens of the eye and the vitreous body. Finally, the light reaches the retina (figure 37).



▶ **figure 37**
cross-section through an eye

The combination of cornea plus lens of the eye plus vitreous body has the same effect as a positive lens: the light is refracted in such a way that a sharp image is created on the retina. As you can see in figure 38, the image is upside down and greatly reduced in size.

The **retina** contains a huge number of light-sensitive sensory cells. These cells give off electrical impulses when light falls on them. The impulses are passed on to the brain by the optic nerve. You only actually see something, when the brain receives these impulses.

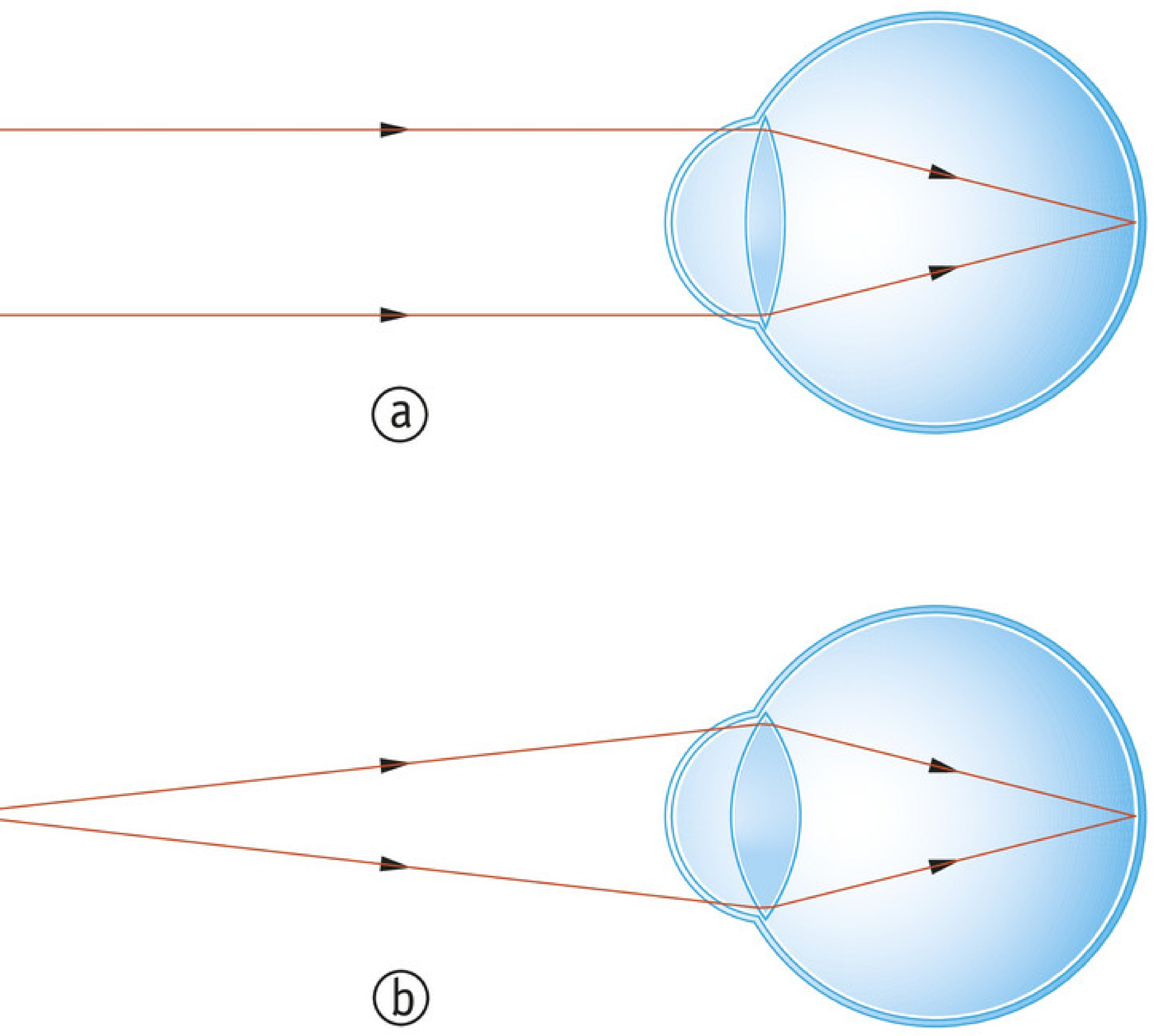


▶ **figure 38**
imaging inside the eye

The **pupil** is an opening in the **iris** (the coloured part of your eye). In bright sunlight, the iris is wide and your pupils are small. This prevents too much light from reaching your retina. In dim light, the iris is narrow and your pupils are large. The small amount of light that is available is then used as well as possible.

Accommodation

The things around you are not all at the same distance. At one moment you are looking at something that is at a distance of half a metre, a few seconds later at something that is a hundred metres away. This means that your eyes, just like a camera or a projector, have to focus.



▲ figure 39
looking in the distance and nearby

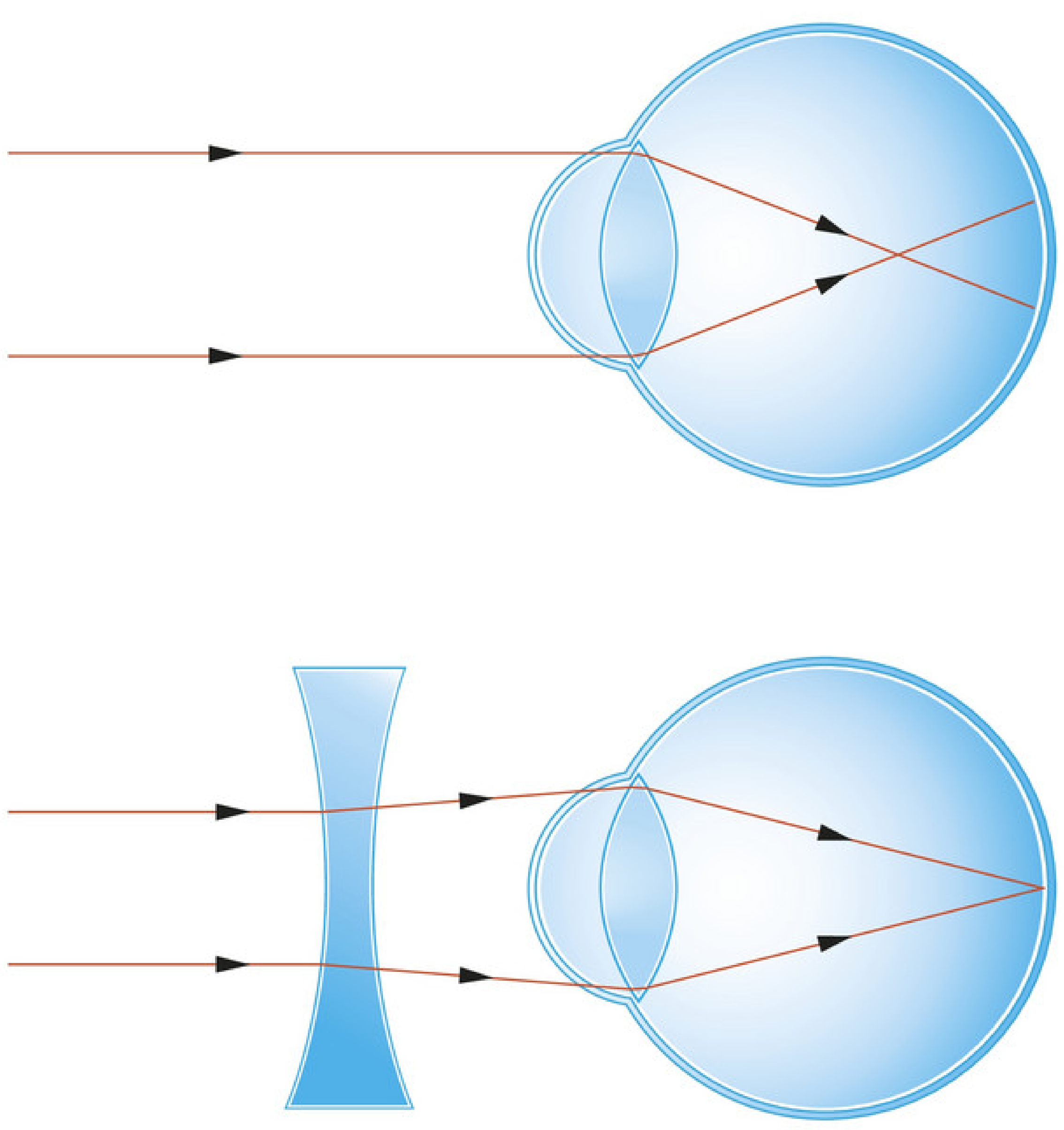
The distance between the lens of the eye and the retina cannot be changed. That is always the same: approximately 17 mm. This means that the image distance *v* is fixed. So in order to focus, your eyes have to adjust their focal length *f*. This is done by a ring of little muscles around the lens of the eye. These muscles can make the lens of the eye more or less convex. This is called the **accommodation** of the eye.

If you are looking at an object in the distance, the muscles are relaxed and the lens of the eye is relatively flat. The focal length is comparatively long. The incident light from the object on the eye is almost a parallel beam in this situation. The lens therefore does not have to be very strong to display a sharp image (figure 39a).

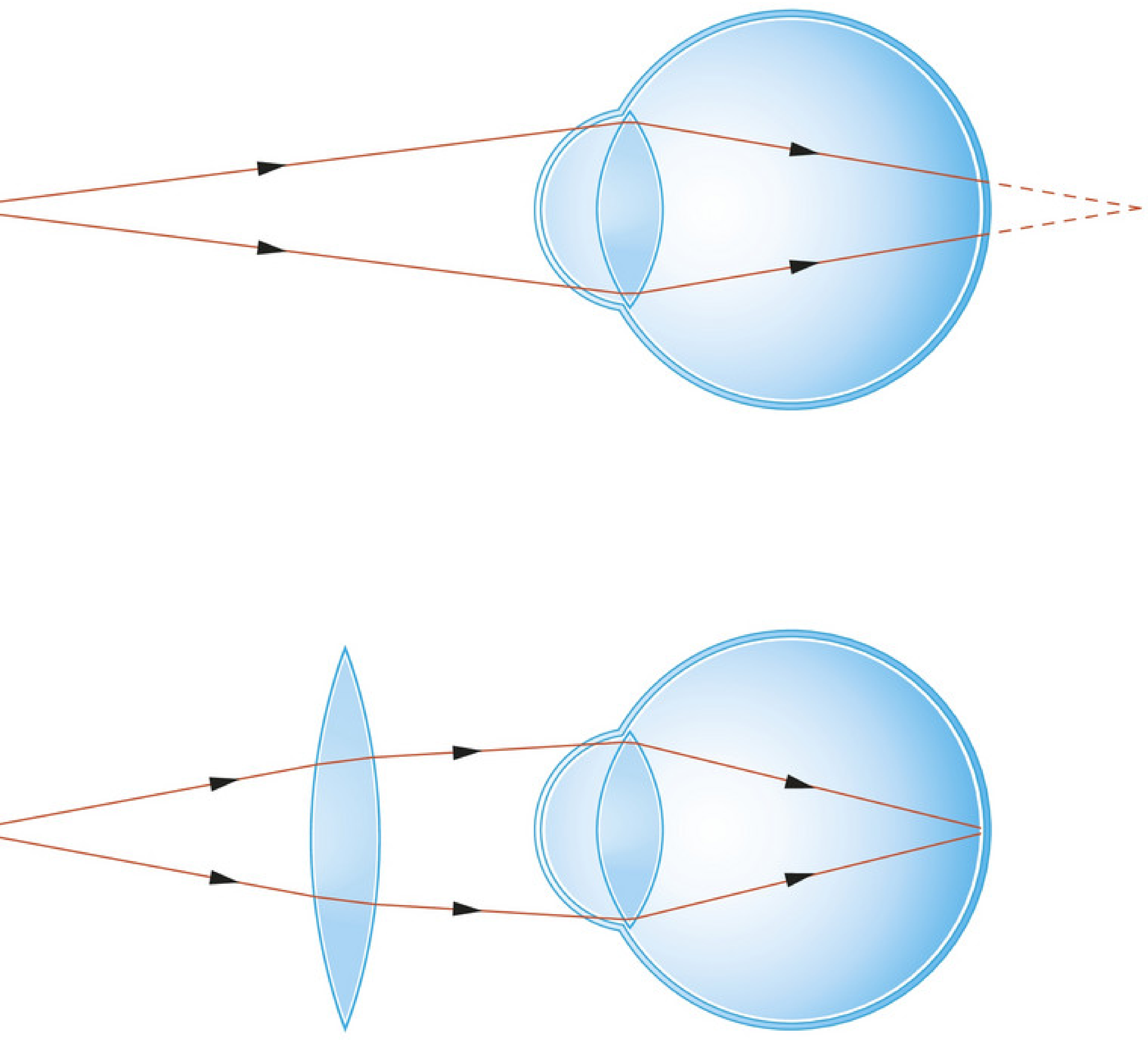
If you are looking at a nearby object, like the screen of your mobile, the muscles around the lens of the eye will contract. As a result, the lens of the eye becomes more convex and the focal length shorter. This is needed because the light that is reaching the eye is diverging a lot. The lens then has to be relatively strong in order to create a sharp image on the retina (figure 39b).

Nearsighted and farsighted

A lot of people do not all see everything around them equally sharp. Their eyes refract the light too strongly, or not strongly enough. They need glasses or contact lenses to correct this problem.


▲ figure 40
Nearsightedness is corrected with a negative lens.

If you are **nearsighted**, the lenses in your eyes are too strong (or the main axis of your eye is too long). You can therefore not see distant objects properly. Figure 40 shows you what the cause is: the lens of the eye does not create the image of the object on the retina, but in front of it. Someone who is nearsighted needs negative spectacle lenses or contact lenses. These make sure that the light reaching the eyes is slightly divergent. The image will no longer be created in front of the retina, but properly on it.



▲ figure 41
Farsightedness is corrected with a positive lens.

If you are **farsighted**, your eye lenses are too weak or your main axis is too short. You can therefore not see nearby objects properly. Figure 41 shows you what the cause is: the lens of the eye does not refract the light enough. If you want to see things in the distance, your eye lenses have to accommodate all the time. This is rather tiring. Someone who is farsighted needs positive spectacle lenses or contact lenses. The light will be more strongly refracted overall, which creates a sharp image on the retina.

Age-related loss of accommodation

Older people often wear reading glasses because they suffer from age-related farsightedness. Their eye lenses are less elastic, so the accommodation is not so good anymore. Their eyes are no longer able to make the lens of the eye convex enough. That is why older people often cannot see things nearby clearly anymore and they need spectacles with positive lenses. To read the small letters in a book up close, they wear 'reading glasses'.

Dioptres

Ophthalmologists and opticians use the dioptre (D) to indicate the power P of spectacle lenses (figure 42). You can determine the power of a lens (in dioptres) as follows:

1 Convert the focal length into metres.
2 Then calculate $1/f$.
3 The resulting number is the power of the lens in dioptres.

The formula is:

$$P = \frac{1}{f}$$

A spectacle lens with a lens power of +2 D therefore has a focal length of 50 cm.

▲ figure 42
Reading glasses in shops always state the power (in dioptres).

Worked example 3
A pair of reading glasses has a focal length of 33 cm.
Calculate the power of the glasses.

data: $f = 33 \text{ cm} = 0.33 \text{ m}$

required: $P = ?$

working: $P = \frac{1}{f} = \frac{1}{0.33} \approx +3.0 \text{ D}$

Plus Laser eye surgery

Swimming or running in the rain is not always much fun for people who wear glasses or contact lenses. To get rid of glasses or contact lenses you can have laser eye surgery. This is a minor surgical procedure. Laser light is used to change the convexity of the lens so that a sharp image can be created on the retina again. The laser light removes tissue by evaporating it away.

A nearsighted eye is made less strong by making the cornea thinner. A farsighted eye is made stronger and more convex by removing the outer edge of the cornea using laser light. This increases the convexity, because the middle part will then be higher than the edges.

New laser eye surgery technology will not make glasses entirely redundant. Once people turn forty, they will start to suffer from age-related loss of accommodation. This is because the lenses of the eyes are getting less flexible. They then have trouble accommodating. Reading glasses will be indispensable to make sure they can see nearby things well.

◀ **figure 43**
Eye laser surgery has to be done very accurately.

Exercises

37 Answer the questions below.

- **a** What exactly is meant by the 'accommodation' of the eye? Explain.
- **b** What shape are the lenses of your eyes when you are looking at a distant object?
- **c** Why can someone who is nearsighted not see distant objects well?
- **d** What kind of spectacle lenses or contact lenses does someone who is nearsighted need?

38 Paul is looking outside, where a car is passing by, and immediately after that he looks at the screen of his phone.

- **a** Explain why Paul can see a sharp image in both situations.
- **b** What needs more of an effort from Paul's eyes: looking outside or looking at his phone? Why?
- **c** In what situation are the lenses of the eyes flattest?

39 You need worksheet 3-10 for this exercise.
In the drawing on the worksheet, Nicholas is holding a match in front of his left eye. He can just focus clearly on the match.
a Draw the image of the match on the retina.
b Is the image magnified or reduced?
c Is the image the right way up or upside down?
d How does the image change when Nicholas holds the match further from his eye?

40 Four situations are described below:
1 You see a plane flying over.
2 You are watching a movie on television.
3 You are trying to find a small splinter in your finger.
4 You are playing a game on a computer.
Put these four situations in sequence, starting with the situation where the lens of the eye is most convex and ending with the situation where the lens of the eye is flattest.

41 Wesley is holding a finger 10 cm away from his eyes. He can still just focus clearly on the finger. The distance between the lens of the eye and the retina is 1.7 cm (both eyes are the same).
a What is the object distance?
b What is the image distance?
c Calculate the focal length.
d Wesley now looks at a car that is driving past 100 m away. What is the object distance now?
e What is the image distance?
f Calculate the focal length.

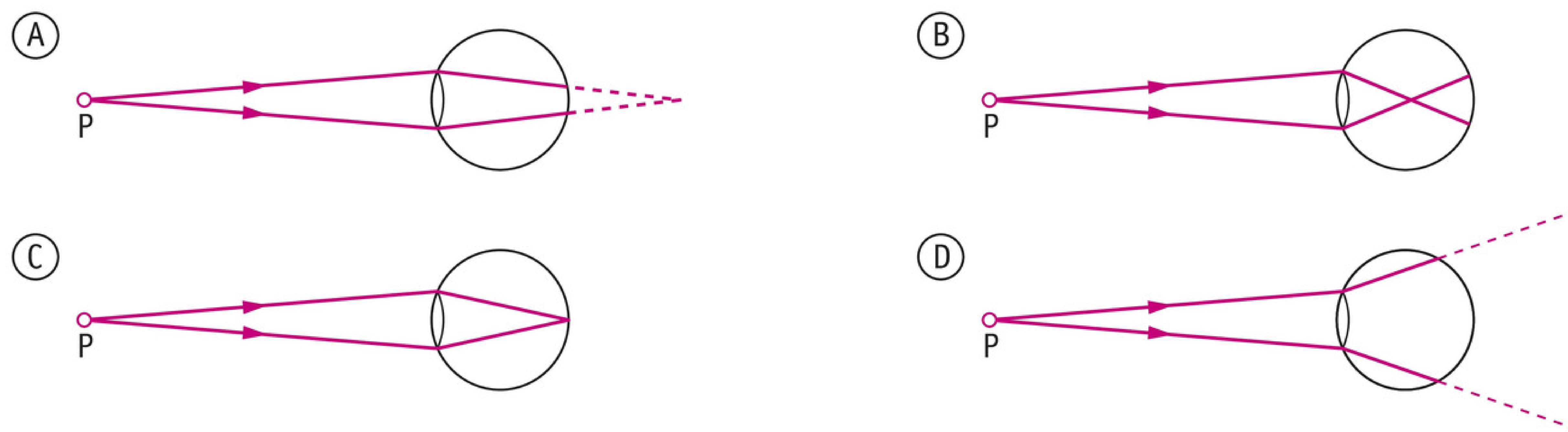
***42** Continuation of exercise 41.
In exercise 41, you calculated the focal length twice.
a In which case are the lenses in Wesley's eyes stronger?
b Wesley looks first at his finger and then at the car. Calculate the percentage change in the focal length of his eye lenses.

43 Jess has fairly strong negative contact lenses.
a Is Jess nearsighted or farsighted?
b Does Jess need her contact lenses for reading?
c Does she need her contact lenses to watch a football match from the stands?

44 Marian cannot see very well without glasses. If an object is more than about 2 m away, she cannot focus the image on her retina. The image is not produced on her retina, but just in front of it.
a Is Marian farsighted or nearsighted?
b What kind of glasses does Marian need?

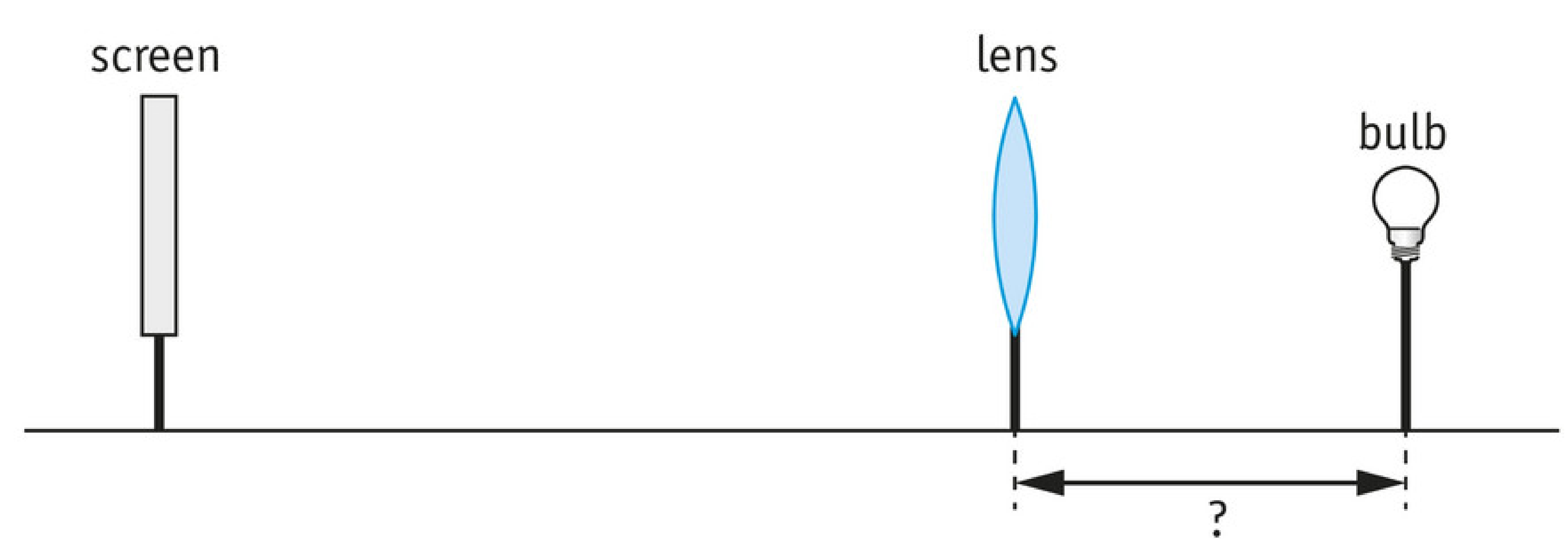
45 The power of Gerard's spectacle lenses is +4 D.
- **a** Calculate the focal length of these lenses.
- **b** Is Gerard nearsighted, farsighted, or does he suffer from age-related loss of accommodation?

***46** Esther is 36 years old. She is looking at the screen of her laptop. Her eye lens is at its maximum accommodation. Even so she does not see the screen clearly, because her eye lens converges the light too little.
- **a** Explain whether Esther suffers from age-related loss of accommoda-tion, or whether she is nearsighted or farsighted.
- **b** Which drawing in figure 44 shows this situation correctly?
- **c** Copy the drawing that you have selected in question b. In this drawing, use a different colour to sketch how the rays will go when Esther puts on suitable glasses.



▶ **figure 44**
Which drawing represents Esther's eye disorder best?

***47** John sets up the experiment shown in figure 45. The power of the lens is +17 D. In the situation drawn, a parallel beam of light falls on the screen.
Calculate the distance from the bulb to the lens.



▶ **figure 45**
John's experimental setup

Plus Laser eye surgery

48 You need worksheet 3-11 for this exercise.
Nathan is 20 years old and can see objects well from nearby, but not when they are far away. He undergoes laser eye surgery to solve this problem. On the worksheet, you can see one of his eyes before the laser eye surgery.
Sketch the shape of the cornea after the laser eye surgery.

49 Keratotomy is a laser irradiation technique sometimes used by ophthalmologists to make a cornea less convex.
Explain which eye disorder can be corrected by keratotomy: nearsightedness or farsightedness.

Experiments

Experiment 1 Refraction of rays 30 min

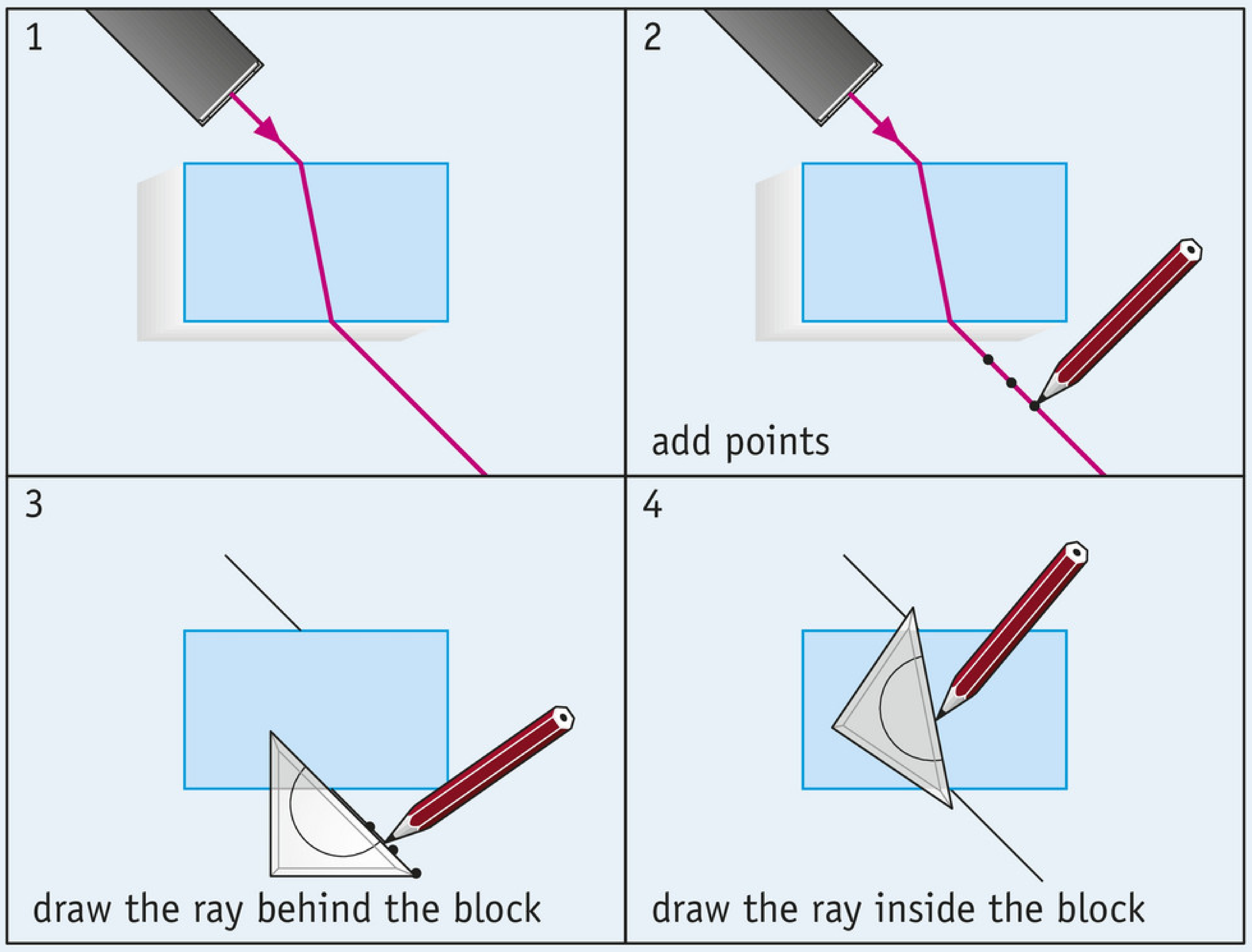
Introduction
If a ray falls on the surface of a transparent substance, something special happens: the light changes direction. This effect is called refraction of light.

Aim
You are going to investigate refraction through a Perspex block.

Requirements
- light box
- diaphragm with a single aperture
- Perspex block
- ruler
- worksheet 3-12

Doing the experiment and writing it up
- Take worksheet 3-12. Put the Perspex cube in the correct position as shown in drawing A.
- Point a beam of light at the block. The actual beam has to follow the same path as the drawn ray.
- Place three dots along the beam that comes out of the block.
- Do the same with the blocks in drawings B and C.

1 On the worksheet, use a ruler to draw how each of the three rays was refracted by the block. See figure 46.
2 In which situation is the beam of light not refracted?
3 In which situation is the beam of light refracted most?
4 You see that reflection can also occur in the Perspex block. Use a cross to indicate on the worksheet where this happens.
5 Wherever refraction occurs, mark in the normal, the angle of incidence and the angle of refraction on the worksheet.



▲ **figure 46**
How to draw rays.

Experiment 2 The relationship between the angle of incidence and the angle of refraction

45 min

Introduction

When rays go from air into Perspex, they are always refracted towards the normal: the angle of refraction ∠*r* (between the refracted ray and the normal) is therefore always smaller than the angle of incidence ∠*i* (between the incoming ray and the normal).

Aim

You are going to determine the relationship between the angle of incidence ∠*i* and the angle of refraction ∠*r* when a ray goes from air into Perspex.

Requirements

- light box
- diaphragm with a single aperture
- semicircular Perspex disc
- ruler
- worksheet 3-13

Doing the experiment and writing it up

Measuring

- Point a ray at the disc, as shown in the drawing in figure 47. The angle of incidence (∠*i*) is then 30°.
- Confirm that the beam of light is only refracted on the transition from air to Perspex (and not on the transition from Perspex to air, on the other side of the semicircle).
- Confirm that the angle of refraction (∠*r*) is 20°.
- Measure the associated value of ∠*r* for seven more values of ∠*i* that are not too close to each other.

1 Copy table 3 and write down the measurements in the table.

▼ **table 3** the relationship between ∠*i* and ∠*r*

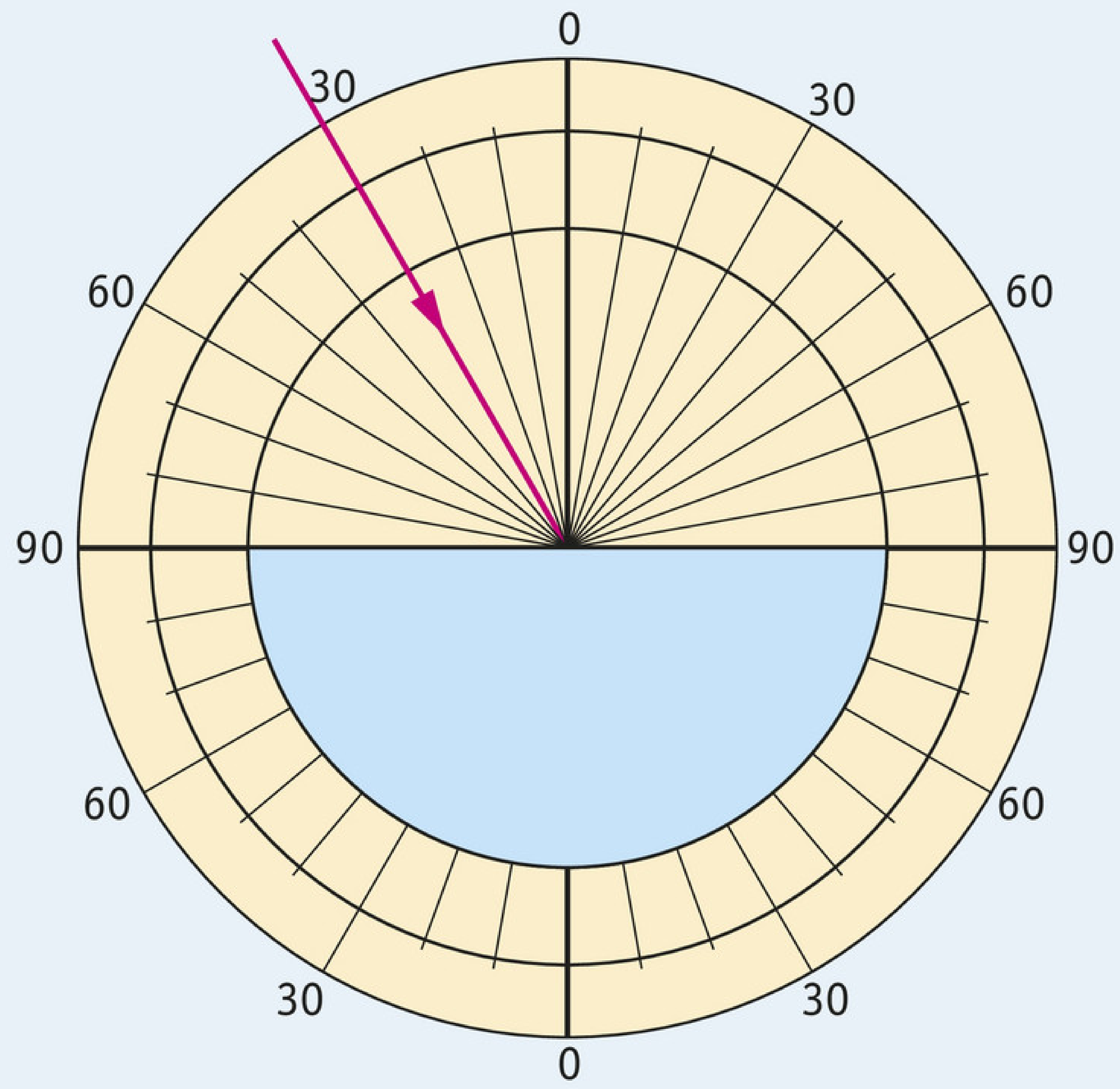
∠*i*	∠*r*
30°	
and so forth	

Writing up

2 Take worksheet 3-13. Draw a graph of your measurements (∠*r* against ∠*i*).

3 Read off from the graph what the angle of refraction is:

a if the angle of incidence is 25°.
b if the angle of incidence is 45°.
c if the angle of incidence is 65°.
d if the angle of incidence is 85°.



▲ **figure 47**
the setup for experiment 2

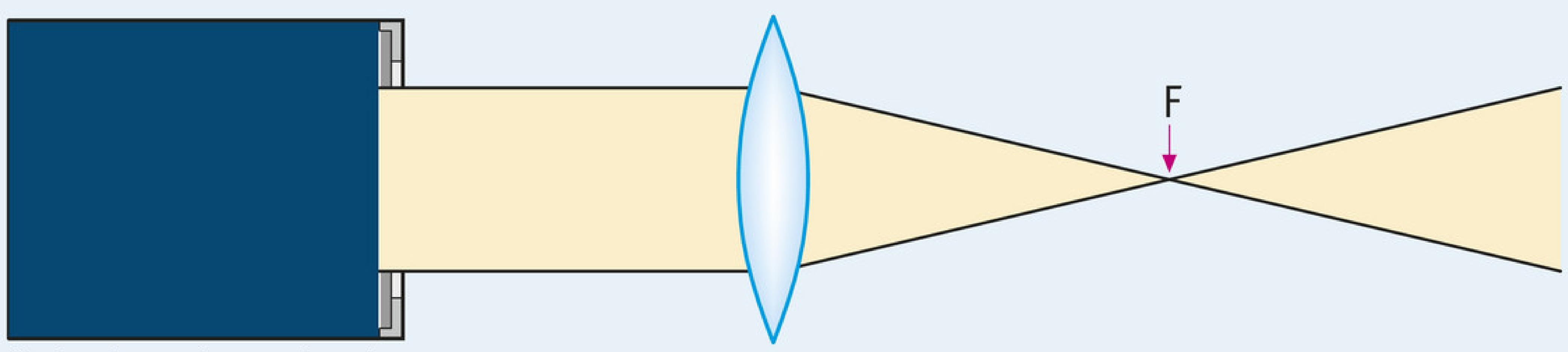
Experiment 3 Finding the focal point 30 min

Introduction
If a parallel beam of light is perpendicular to a lens, the light will be refracted towards one point. This point is called the focal point. The distance between the centre of the lens and the focal point is called the focal length. The stronger the lens, the shorter the focal length.

Aim
You are going to determine the focal lengths of a variety of positive lenses.

Requirements
- light box
- several positive cylindrical lenses
- a sheet of white paper

▼ **figure 48**
How to place a lens in the parallel beam of light.



Doing the experiment and writing it up
– Use the light box to create a parallel beam of light on the sheet of white paper by moving the bulb in the light box. Make sure that the beam of light is small enough (a few centimetres) so that it is narrower than the smallest lens. Check that the beam of light is really parallel.
– Put a positive lens on the sheet of white paper in the parallel beam of light (see also figure 48). Point the parallel beam of light at the lens, first from the left and then from the right.
– On the paper, indicate the position of both the focal points of the lens using a dot.

1 Determine the value of the focal length for each lens. Explain how you have determined it.
2 Rank the lenses according to their power: the least strong lens first.
3 You could have predicted which lens would be the strongest.
How?

Experiment 4 Divergent and convergent 20 min

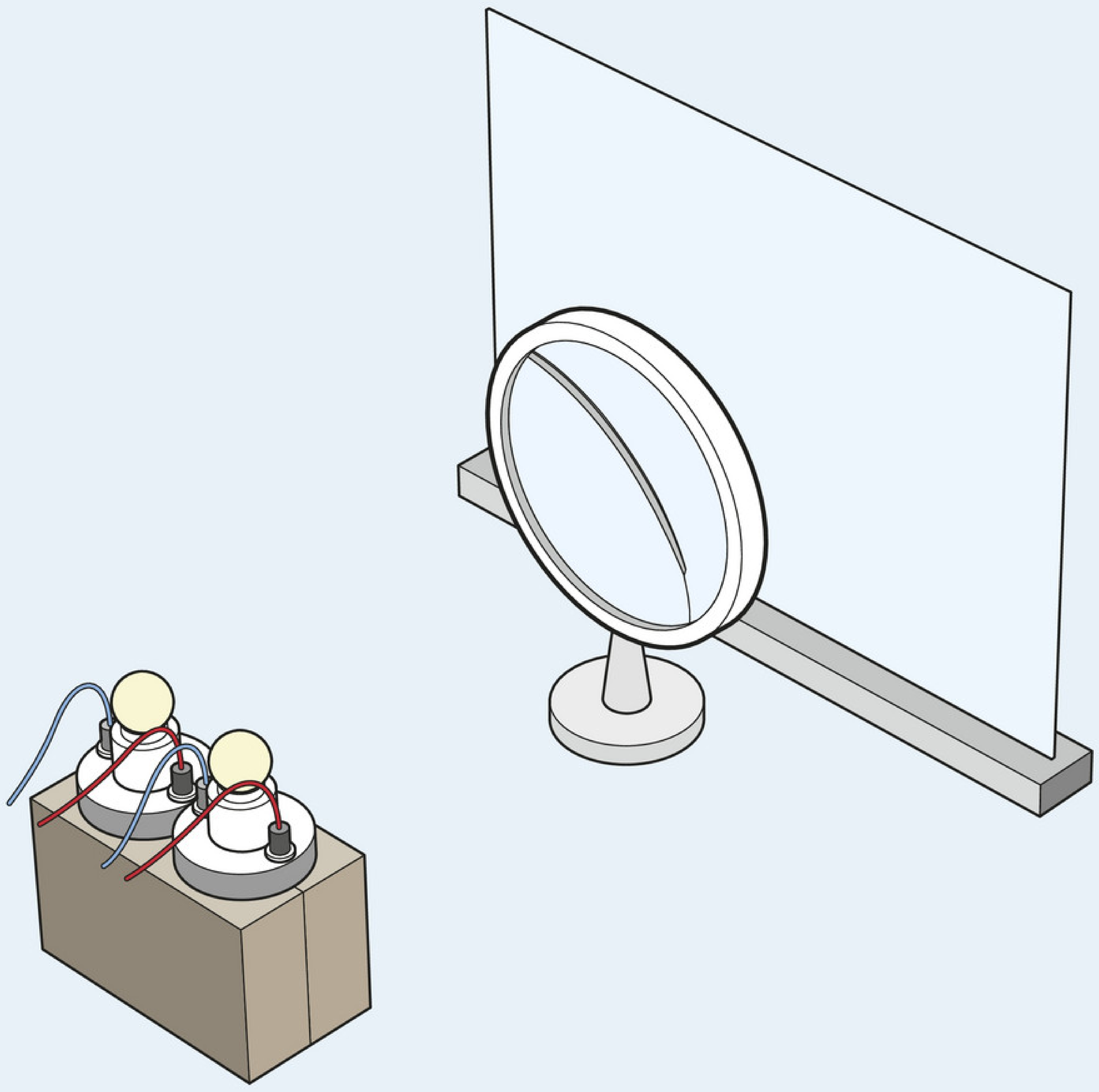
Introduction
You can project the images of two bulbs onto a screen using a positive lens. If the screen is in the right position, the image will be sharp. Every point on the object (the bulbs) is displayed as a point on the screen.

Aim
You are going to investigate how a sharp image like this is created.

Requirements
- positive lens (f = 10 cm)
- lens holder
- screen
- 2 bulbs
- 2 fittings
- battery
- 2 wires
- ruler

Doing the experiment and writing it up

- Set up the experiment as shown in figure 49.
- Put the lens 15 cm from the bulb.
- Put the screen 5 cm behind the lens.



▲ **figure 49**
the setup for experiment 4

1 Measure the diameter of one of the spots of light that you see on the screen.

- Move the screen 5 cm further away from the lens.

2 Are the spots of light getting larger or smaller?
3 Is the light diverging here or is it converging?

- Move the screen a little further back. Find the point where the spots of light are smallest. At that point you can see a sharp image of both bulbs.

4 Are the projected images of the bulbs the right way up or upside down?

- Cover the left-hand bulb with your hand.

5 Which bulb disappears from the image: the left-hand one or the right-hand one?

- Hold one bulb above the other.
- Cover the upper bulb with your hand.

6 Which bulb disappears from the image now: the lower one or the upper one?

- Move the screen another 10 cm away from the lens. Look at the spots of light that you see on the screen now.

7 Are the beams divergent or convergent at this point?
8 Read your answers to questions 1 to 7 again.
a Describe how the spots of light change as you move the screen further and further away from the lens.
b Explain why the spots of light change in that way. Use the words ‘convergent’ and ‘divergent’. Tip: make a sketch with your explanation.

Experiment 5 The lens equation 45 min

Introduction

You can use a positive lens to create an image of an object on a screen. The relationship between the object distance u, the image distance v and the focal length f for a sharp image is given by the lens equation.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Aim

You are going to check the lens equation by performing a series of measurements.

Requirements

- optical bench
- light source with a slide
- positive lens (f = 10 cm)
- lens holder
- screen

Doing the experiment and writing it up

– Set the experiment up as shown in figure 50.
– Set the object distance u to 12.0 cm.
– Move the screen back and forth. Find the position where the image is sharpest.
– Measure the image distance v.

1 Copy table 4 into your exercise book. Make a note of the measured image distance in column 2 of the table.

– Choose at least four other values for u between 12.0 and 30.0 cm. Calculate for each value of u the associated image distance v.

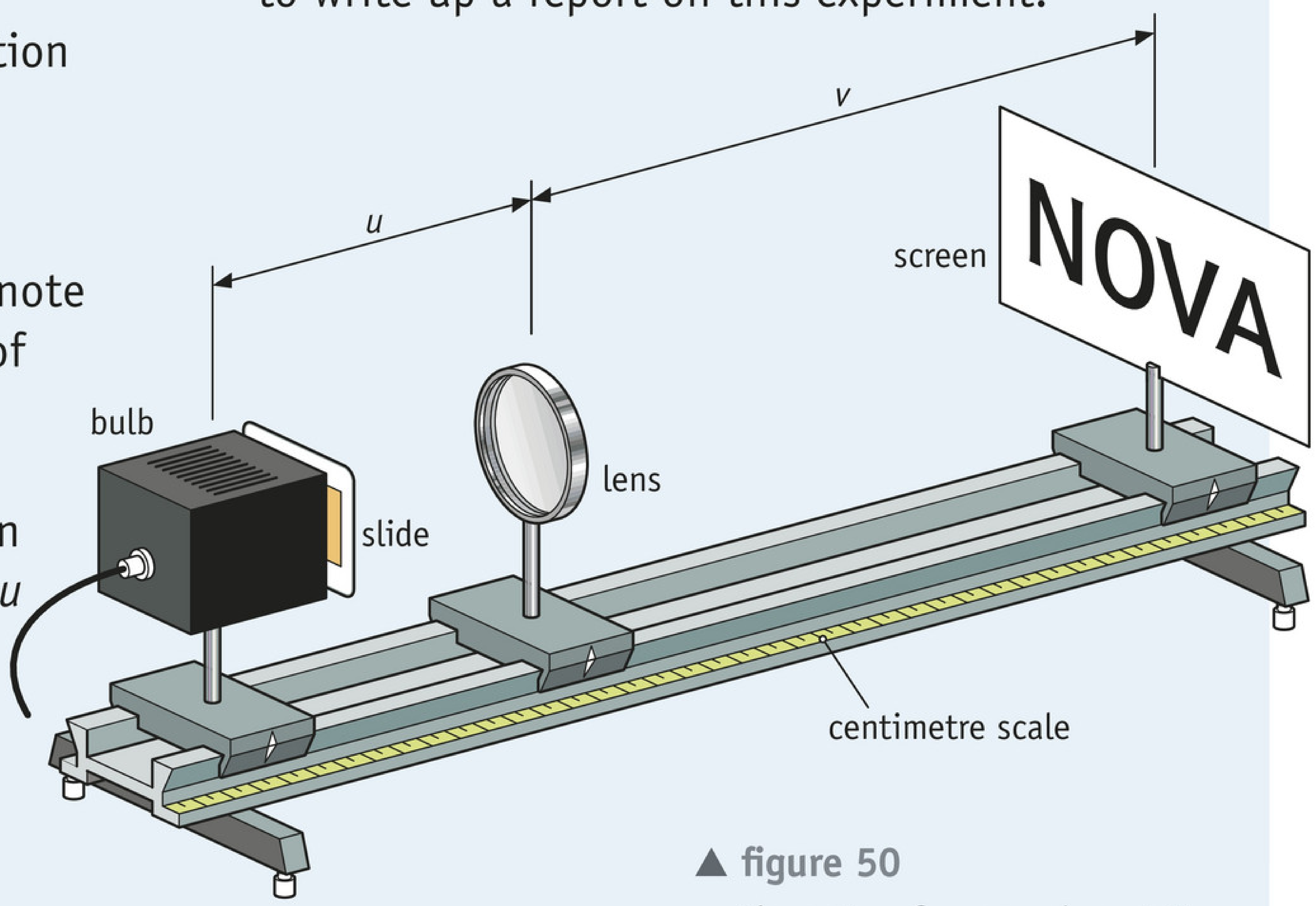
2 Make a note of your measurements in columns 1 and 2 of the table.

3 Complete the table.
  a Work out $1/u$ using your calculator. Round off the result to three decimal places and write down the value in column 3.
  b Work out $1/v$ using your calculator. Round off the result to three decimal places and write down the value in column 4.
  c Add the numbers in columns 3 and 4. Put the result in column 5.
  d According to the lens equation, the number in column 5 should be equal to $1/f$. You can therefore calculate $1/f$ by 'inverting' the number in column 5 (using the reciprocal function, the $1/x$ button on your calculator). Put the result in column 6.

4 Calculate the average of the values of f that you have found and write it down below the table.

5 Ask your teacher for the actual value of f for the lens according to the manufacturer.
Calculate the percentage error in your (average) value.

– Your teacher will tell you whether or not you have to write up a report on this experiment.



▲ **figure 50** the setup for experiment 5

▼ **table 4** the lens formula

u	v	$1/u$	$1/v$	$1/u + 1/v$	f
12.0 cm					
and so forth					

Experiment 6 Producing a design – the telescope 90 min

Introduction
Suppose you are doing an astronomy project at school. Your exercise is to design a telescope or a pair of binoculars that you can use to view the craters on the Moon in the evening.

Aim
You are going to design, build and test a telescope. Your prototype must meet the following design requirements:

Design requirements
- The telescope consists of two positive lenses (the eyepiece lens close to your eye and the objective lens at the other end).
- When you look through the telescope you will see a sharp and magnified image of the starry sky.
- The telescope is sturdy and made of materials that can be replaced easily and cost little or nothing.
- The magnification range of the telescope can be changed using various objective lenses that can be replaced and set easily.

Requirements
You have to think up for yourself what equipment you will need for this experiment. Discuss it if necessary with your teacher.

Doing the experiment and writing it up
– Search the Internet for information about telescopes that you can make yourself. Check what the function of the eyepiece lens and the objective lens is and how you have to position these lenses to get a sharp image.

1 See 'Skills 9' at the back of the book. Make a work plan for this study.

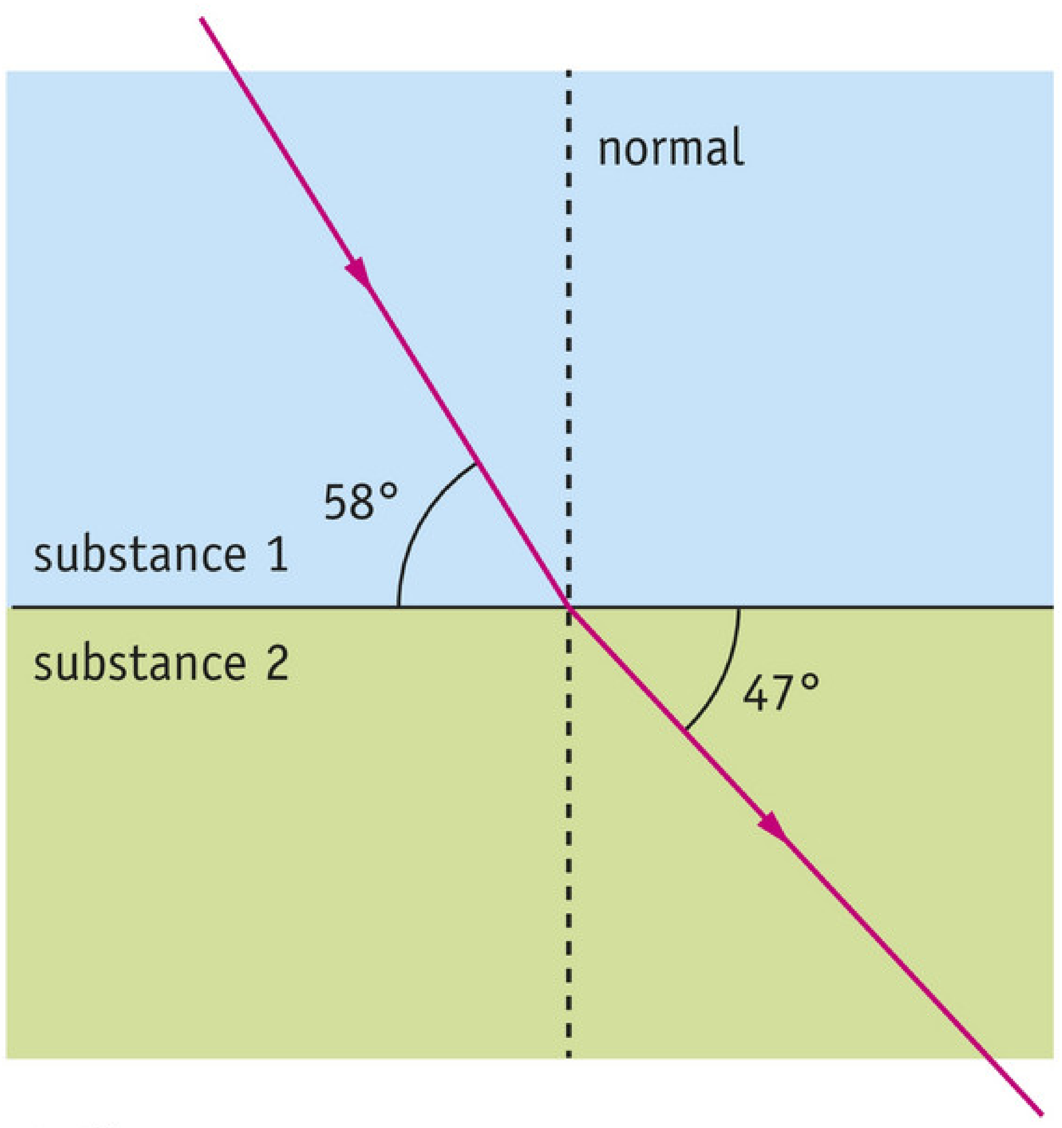
– The work plans will be discussed with the rest of the class at the next lesson. If necessary, you can make improvements to your own work plan after that.
– Build the telescope according to the design requirements and try it out.

2 Make a test report that includes:
- **a** a clear diagram showing how the telescope is constructed;
- **b** a list of the materials you used;
- **c** the tests you carried out to get a sharp image;
- **d** a clear explanation of how you can vary the magnification.

Test Yourself

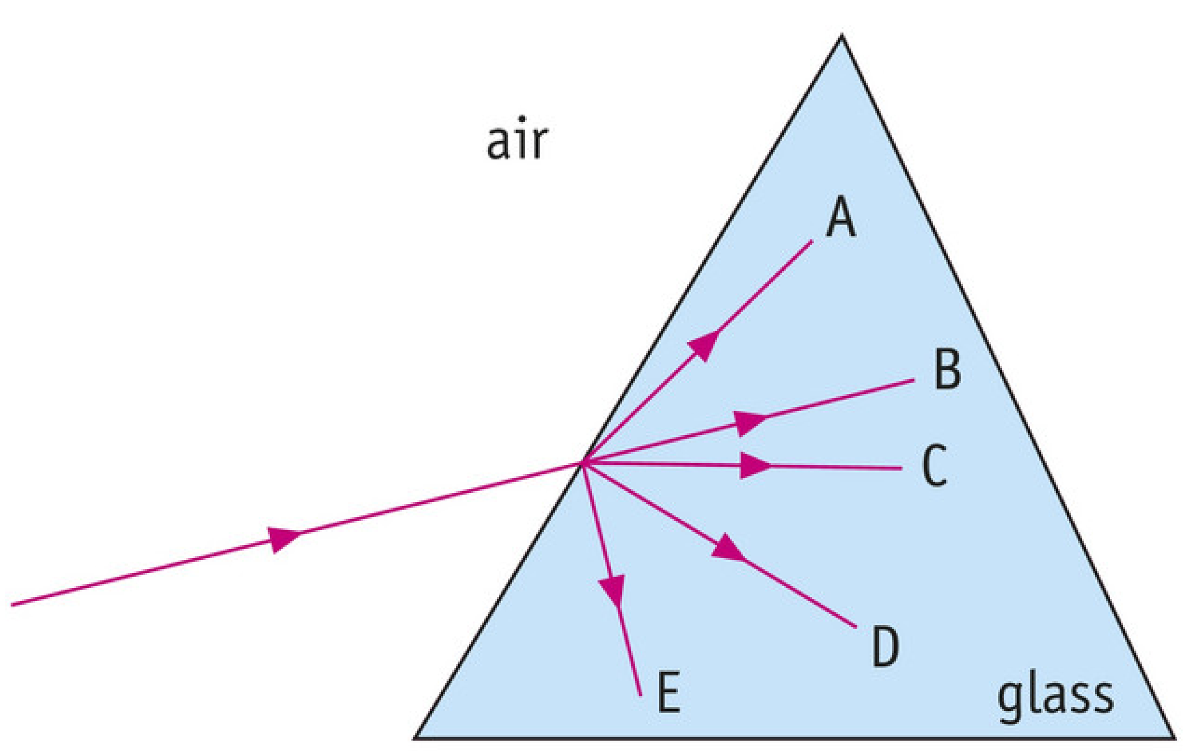
You can also do questions 1 to 16 on the computer.

1 A ray moves from substance 1 to substance 2 (figure 51). One of the substances is air and the other is glass.
- **a** What is the angle of incidence?
- **b** What is the angle of refraction?
- **c** Which substance is air and which is glass?



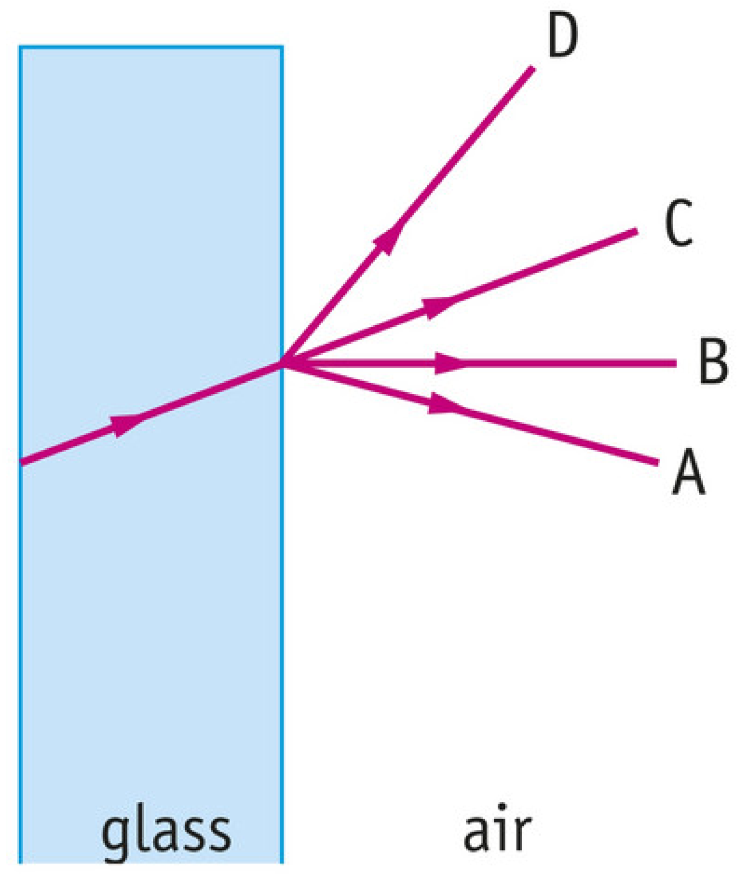
▲ **figure 51**
refraction from substance 1 to substance 2

2 A ray falls on a glass prism (figure 52).
How does the ray progress after that: along A, B, C, D or E?



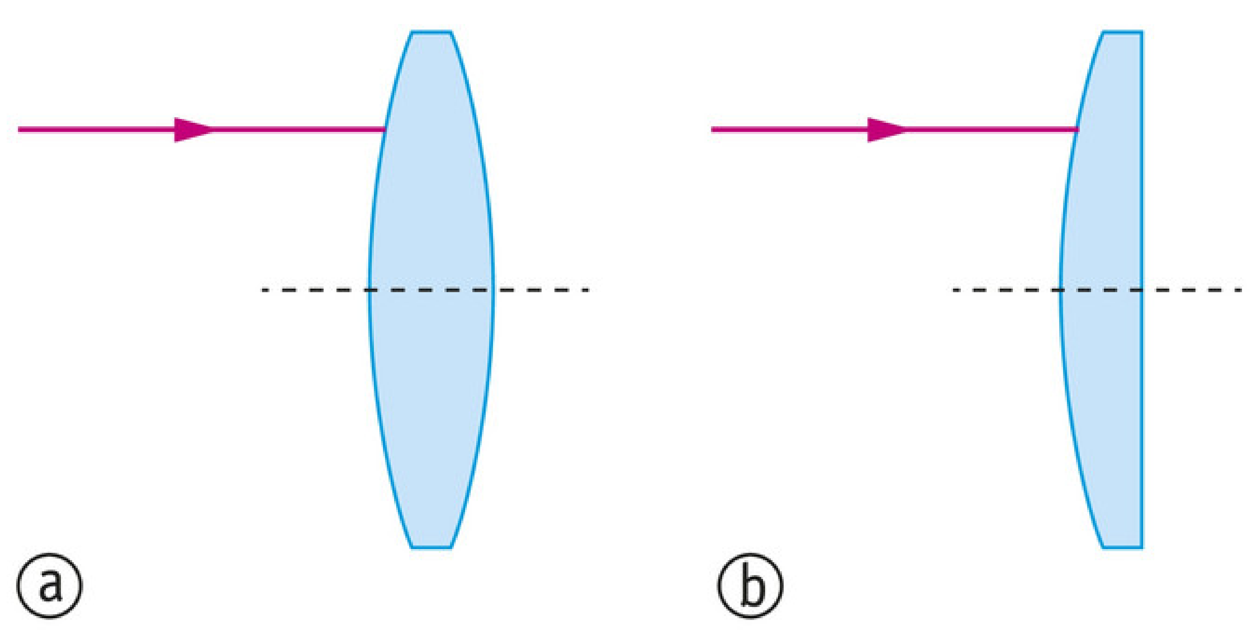
▲ **figure 52**
refraction through a prism

3 A ray hits the boundary between glass and air (figure 53).
How does the ray progress after that: along A, B, C or D?



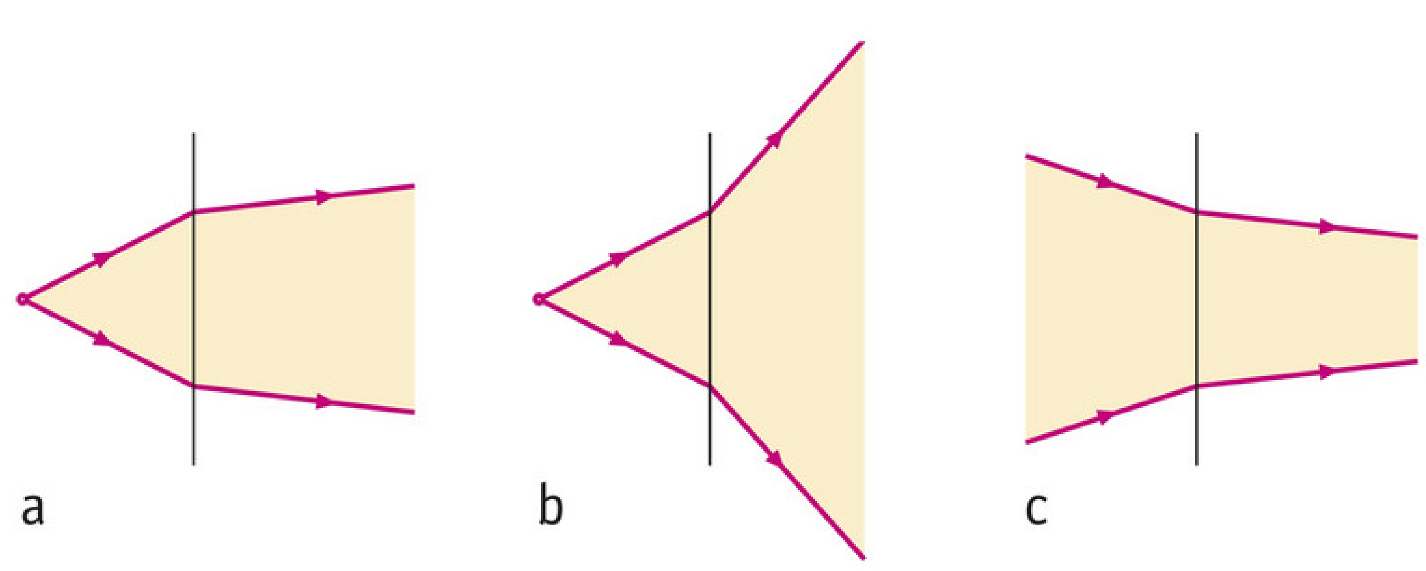
▲ **figure 53**
refraction through a sheet of glass

4 Figure 54 shows two lenses. A ray parallel to the main axis falls on each lens.
- **a** Which lens refracts the ray most?
- **b** Which lens has the longer focal length?

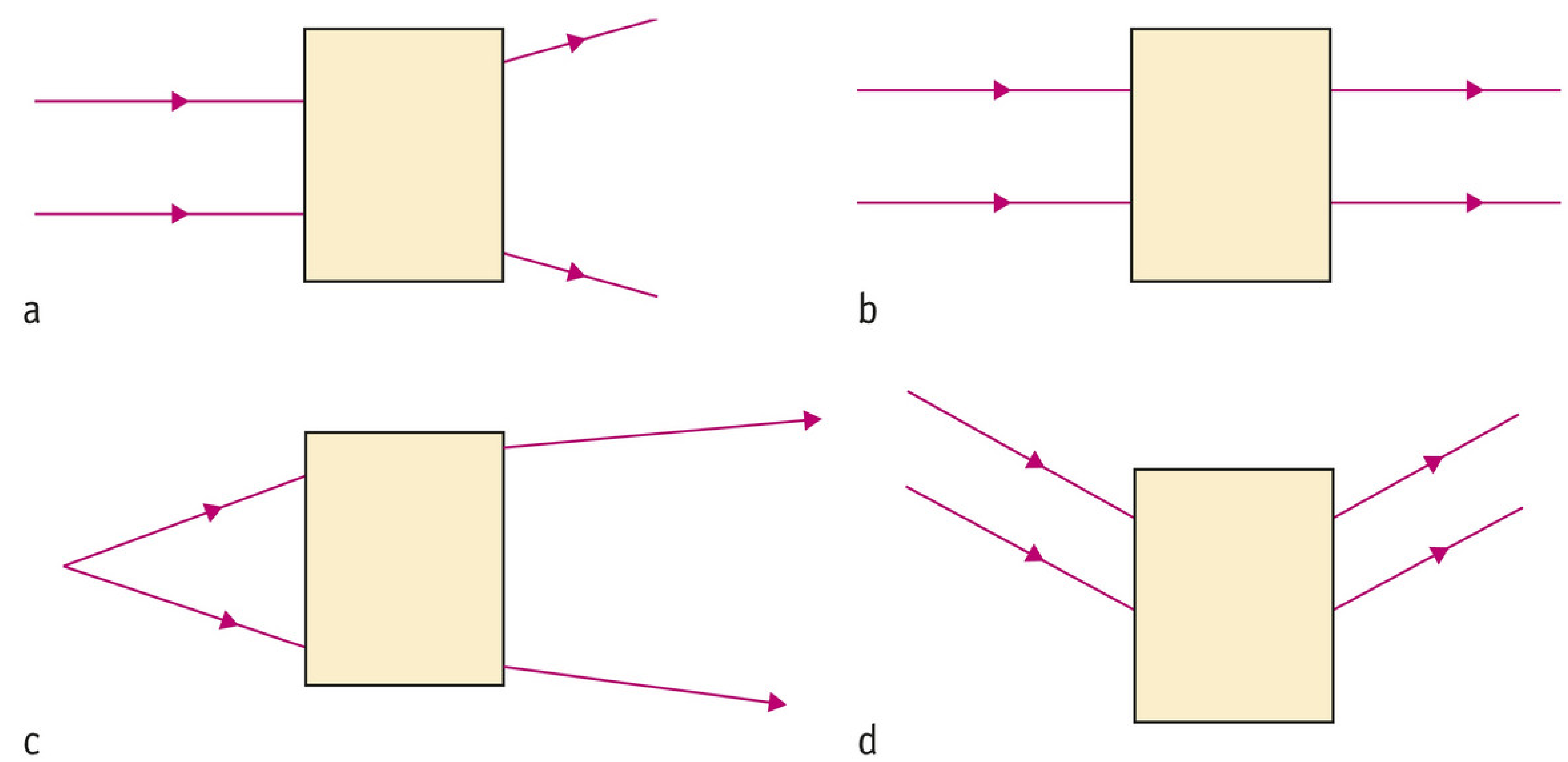


▲ **figure 54**
two lenses

5 Figure 55 shows you how three lenses refract an incoming beam of light.
For each lens, state:
- if it has a converging or diverging effect.
- if it is a negative or positive lens.



▶ **figure 55**
convergence and divergence



▶ figure 56
What is in each tube?

6 Figure 56 shows four tubes.
– One tube contains nothing at all.
– One tube contains a concave lens.
– One tube contains a convex lens.
– One tube contains a mirror.
State what is in each of the tubes.

7 The light from a small bulb falls on a positive lens. Behind the lens, this light converges at one point.
What do you call this point?
A the image point
B the focal point
C the object point
D the centre of the lens

8 You can project the image of an object onto a screen using a positive lens.
Imogen says, “Compared with the object, the image is always upside down.”
Rosemary says, “Compared with the object, the image is always reduced.”
Which statement below is correct?
A Imogen and Rosemary are both right.
B Imogen is right but Rosemary is wrong.
C Imogen is wrong but Rosemary is right.
D Imogen and Rosemary are both wrong.

9 Zoe uses a positive lens to project a sharp image of a bulb on a screen. The distance between the bulb and the lens is 15 cm and the distance between the screen and the lens is 7.5 cm.
Calculate the focal length of the lens.

10 Alex is using a projector to show photos. The photo on the screen is 180 cm wide and 135 cm high. The magnification is 60×.
How large is the image on the LCD screen inside the projector?

11 Nick has set up an experiment using a positive lens (f = 12 cm). In front of the lens there is a burning candle that is 10 cm high. A screen 36 cm behind the lens, shows a sharp image of the candle flame.
a Calculate the object distance.
b The flame of the candle is 1.4 cm high. Calculate the size of the image.

12 Ingrid is walking around Rotterdam where she admires the Euromast. Then she looks at the screen of her phone to find information about the Euromast.
a Will the lenses in Ingrid’s eyes become more or less convex when she moves her eyes to the screen?
b Will the focal length of her eye lenses be longer or shorter when she does this?

13 The lenses of Pauline’s eyes do not refract light strongly enough. That is why she wears contact lenses.
a What is the name for Pauline’s eye problem: is she nearsighted or farsighted?
b Are the contact lenses that Pauline wears positive or negative?

14 Robert wears spectacles. His left spectacle lens has a focal length of 40 cm.
Calculate the power of the left spectacle lens in dioptres.

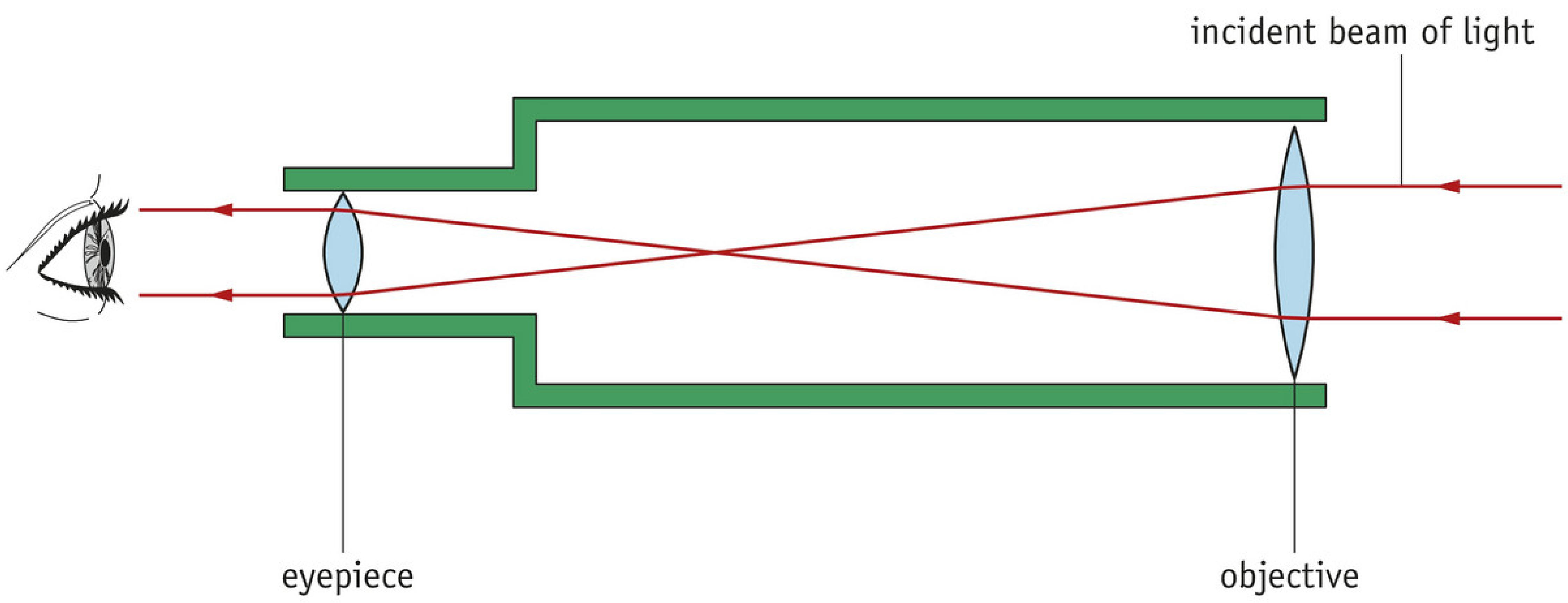
15 State whether the following statements are true or false.
- **a** You focus your eyes by adjusting the image distance *u* to fit the situation.
- **b** Changing the shape of the lens of the eye is called accommodation.
- **c** Your eye lenses are flattest when you are looking at something small from very close by.
- **d** When someone is farsighted, the eye lenses are too strong and/or the main axis is too long.
- **e** Someone who is nearsighted needs positive spectacle lenses or positive contact lenses.

***16** The power of Naima's unaccommodated eyes is 50 D.
Calculate the distance between the eye lens and retina in mm.

***17** Fatima is using a projector to show photos. The projection screen is 8.0 m from the lens and this creates an image magnified 70×.
Calculate the focal length in cm. Round off to three decimal places.

18 Figure 57 shows you a simplified drawing of a telescope. The telescope has two lenses, the objective and the eyepiece.
Explain:
- **a** whether the objective is a positive or a negative lens.
- **b** whether the eyepiece is a positive or a negative lens.
- **c** which lens has the shorter focal length.
- **d** which lens refracts the light most.

▼ **figure 57**
a simple telescope

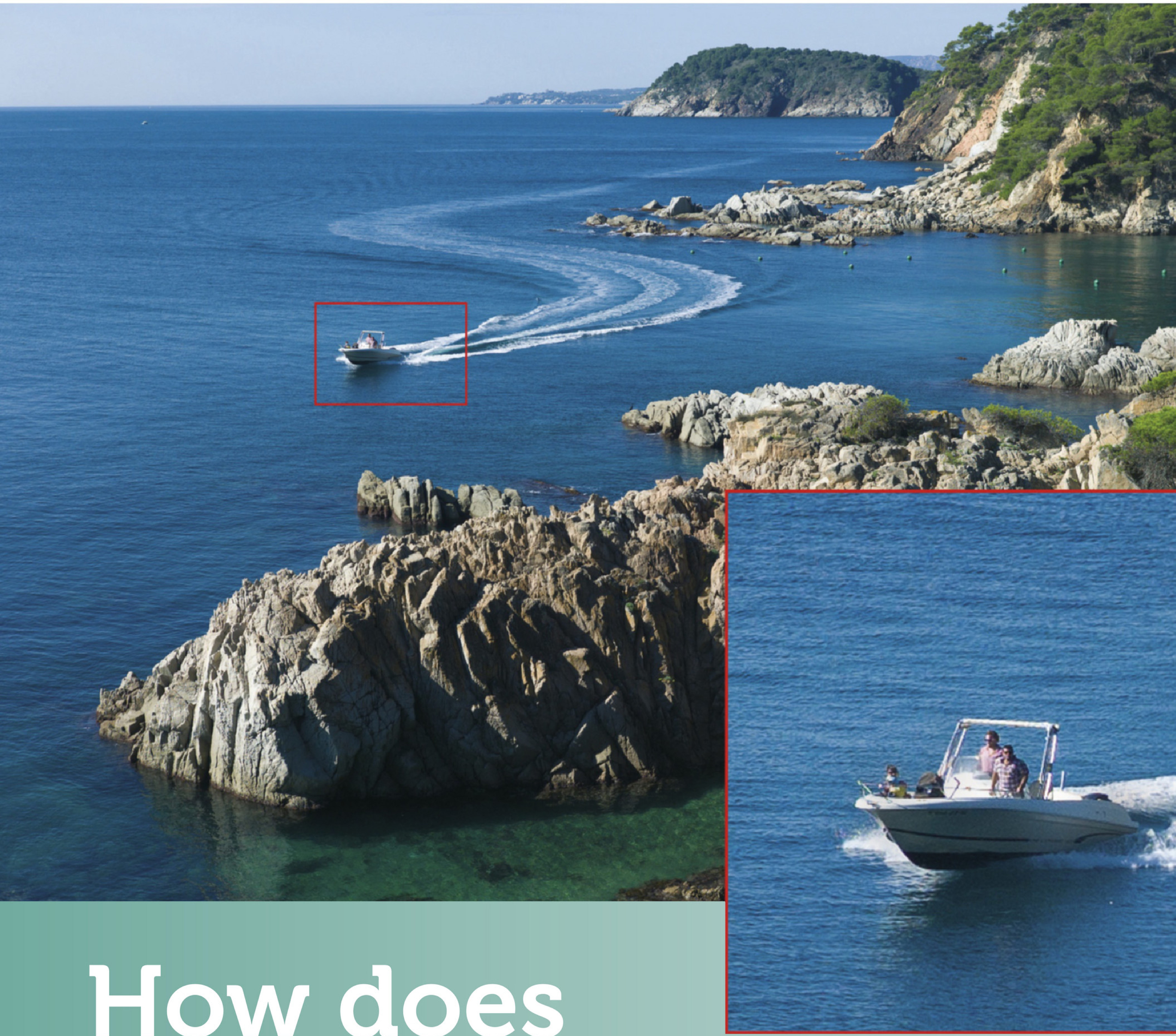


19 You need worksheet 3-14 for this exercise.
Helen is carrying out an experiment using on optical bench. The worksheet shows a schematic drawing of the setup for her experiment.
- **a** Construct the image of the arrow.
- **b** Determine the magnification.

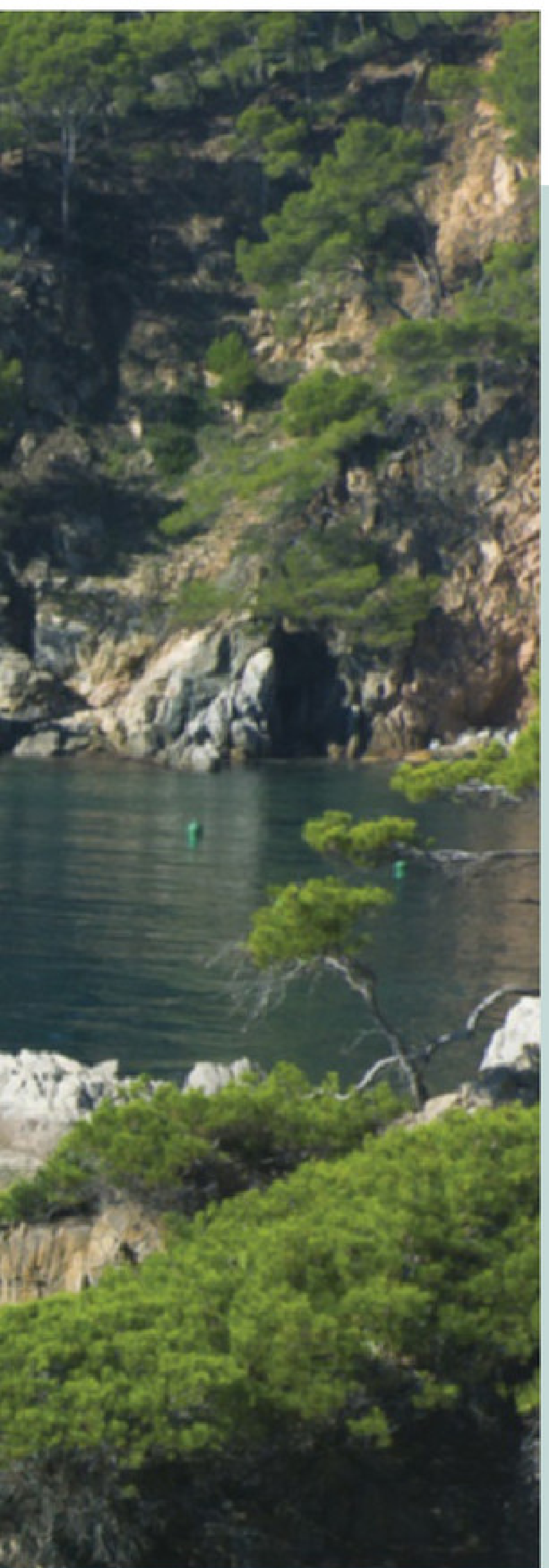
20 You need worksheet 3-15 for this exercise.
A projector creates an image on a smartboard at the front of the class. The worksheet shows a schematic drawing of the LCD screen and the smartboard. The image fills the entire smartboard, right up to its edges.
- **a** Use the construction rays to find out:
  - where the lens is.
  - where the focal point is.
- **b** Draw the lens at the correct point as a vertical line.
- **c** Put a dot where the focal point is and label it with a capital letter F.

21 Figure 58 shows Mr and Mrs Lamb who are on holiday together.
Explain whether one of the two:
- **a** is nearsighted.
- **b** suffers from age-related loss of accommodation.
- **c** is farsighted.

▲ **figure 58**
Mr and Mrs Lamb do not see very well anymore.



How does a camera work?



You can take razor-sharp photos with a good camera. You can only see how sharp the image is when you look at the photo after it has been magnified. You then discover all kinds of details that can hardly be seen without magnification. You do not have to be a skilled photographer to take a photo like that. Watch well and click correctly – that's all you have to do. The camera is full of technology that does all the work for you.

The heart of the camera consists of an image sensor of no more than 2.4 × 3.6 cm, and usually even smaller than that. The image sensor chip is divided up into millions of areas called pixels. When you take a photo, each pixel records a little piece of the image.

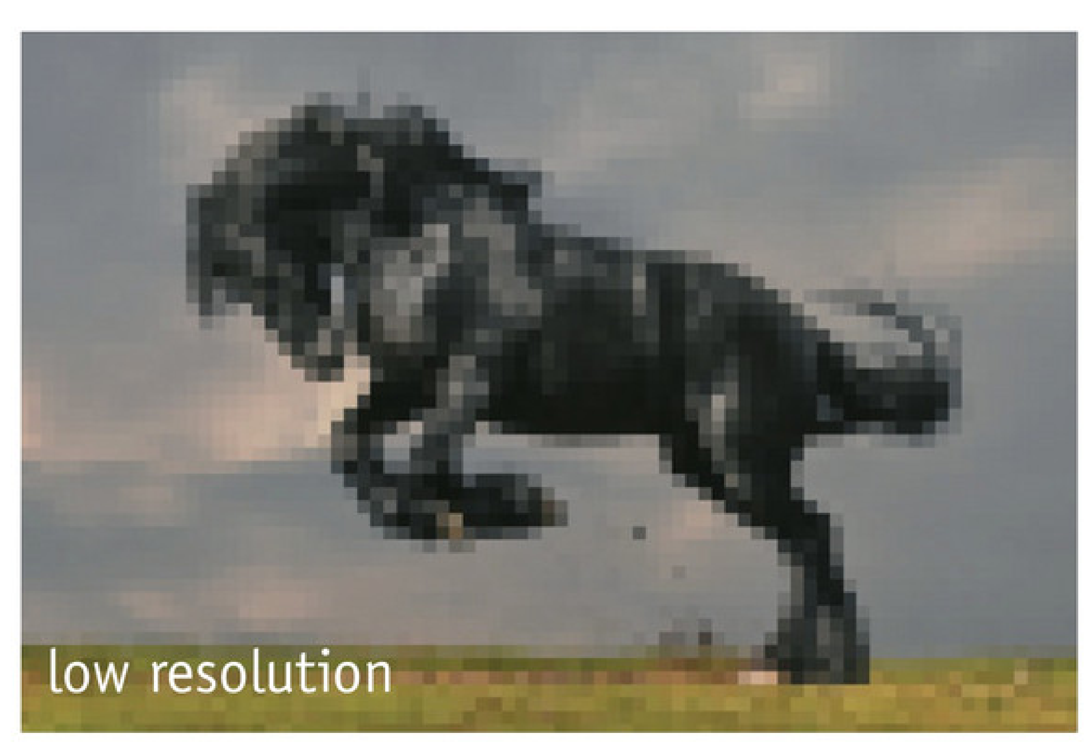
The computer in the camera uses the information from the pixels on the image sensor to create one file. You can put this file on your computer and view it greatly magnified. Then you can see that the image is entirely made up of separate little 'blocks'. Those are the pixels of which the image is made up.

The number of pixels that the image consists of is called the resolution. The higher the resolution, the more detail the image may have. But note, we say 'may have'. The photo has to be sharply focused for this. If you magnify a blurred photo, you will not see any clear details, but only vague patches of colour. The resolution of cameras is expressed in megapixels. A camera of 25 megapixels (25 MP) creates photos with 25 million pixels. You can magnify that kind of photo a lot and the quality of the image will not be noticeably less.

Displaying colours

If you store a photo as a jpeg file (a popular file format for photos), three values will be recorded for each pixel: the first number indicates the amount of red light, the second the amount of green

high resolution



low resolution

and the third the amount of blue. Based on this information, a screen that works with red, green and blue light can display the photo correctly.

You might think that the pixels on the image sensor are sensitive to different colours of light, but that is not the case. The actual pixels are colour-blind: they only react to the intensity of light. To make sure that the colours in the image can still be recorded, a colour filter is used.

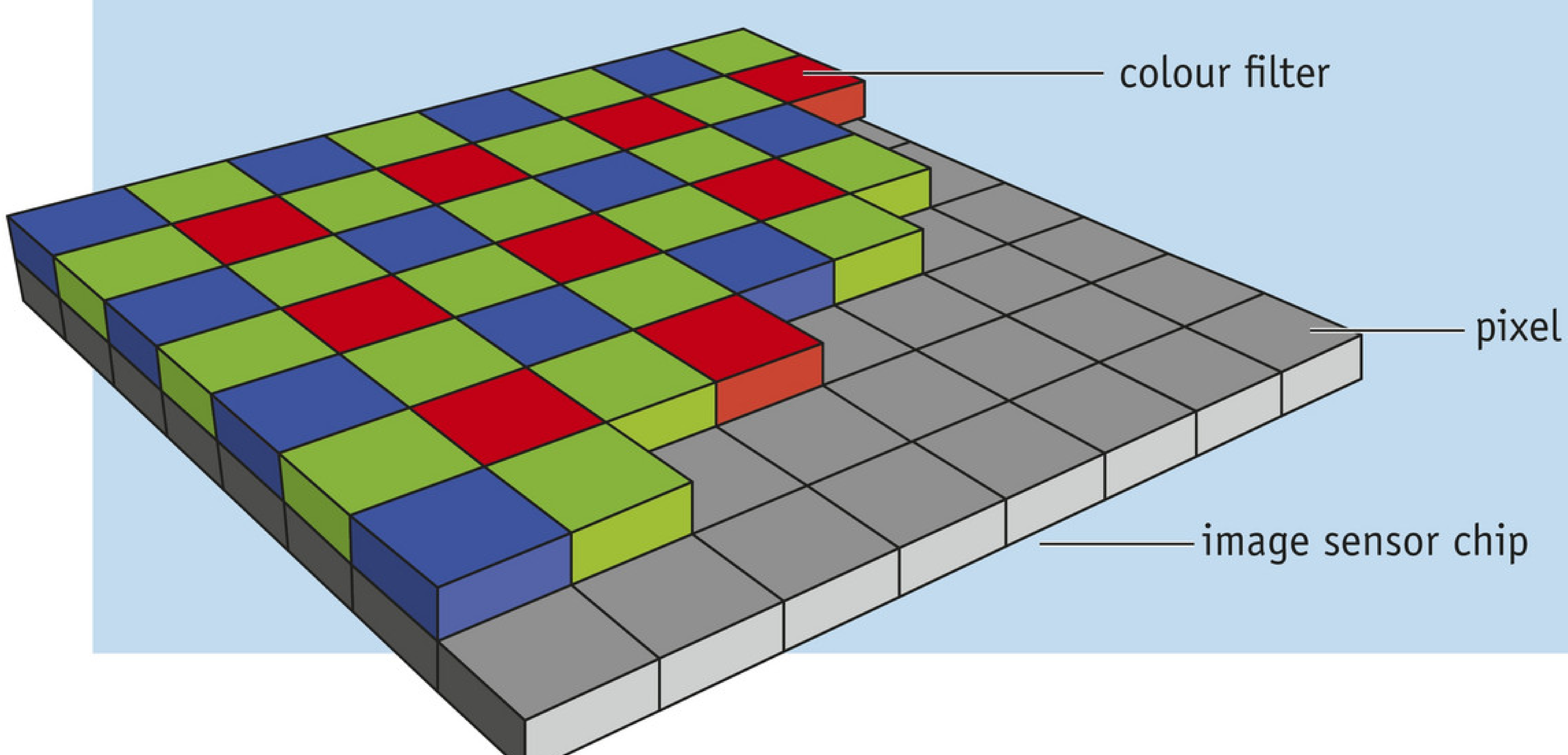
Most cameras have a filter that is made up of tiny red, green and blue squares. There is exactly one tiny square in front of each pixel on the image sensor. Each pixel therefore has its own individual filter square that it receives light through. The red squares allow (almost) only red light to pass. The pixels underneath a red square therefore only record information about the amount of red light. The pixels underneath green squares do the same for green light, and the pixels underneath blue squares do the same for blue.

The information given by the image sensor is therefore not complete. Each pixel only gives information about one colour of light: red, green or blue. A complex computer process is needed to make sure that the image is complete. The software uses the information from neighbouring pixels to calculate the two missing colour values. This makes it possible to record three colour values for each pixel.

The greater the resolution, the more detail the picture can show.

SIXTEEN MILLION COLOURS

The numbers recorded in a jpeg file range from 0 to 255. The intensity of red can therefore be recorded in 256 gradations: from 0 (no red) to 255 (red at full intensity). The same goes for green and blue. A total of 256 × 256 × 256 different mixes of colours can therefore be recorded – more than 16 million in total. As a rule, this is enough for any colour to be displayed properly.

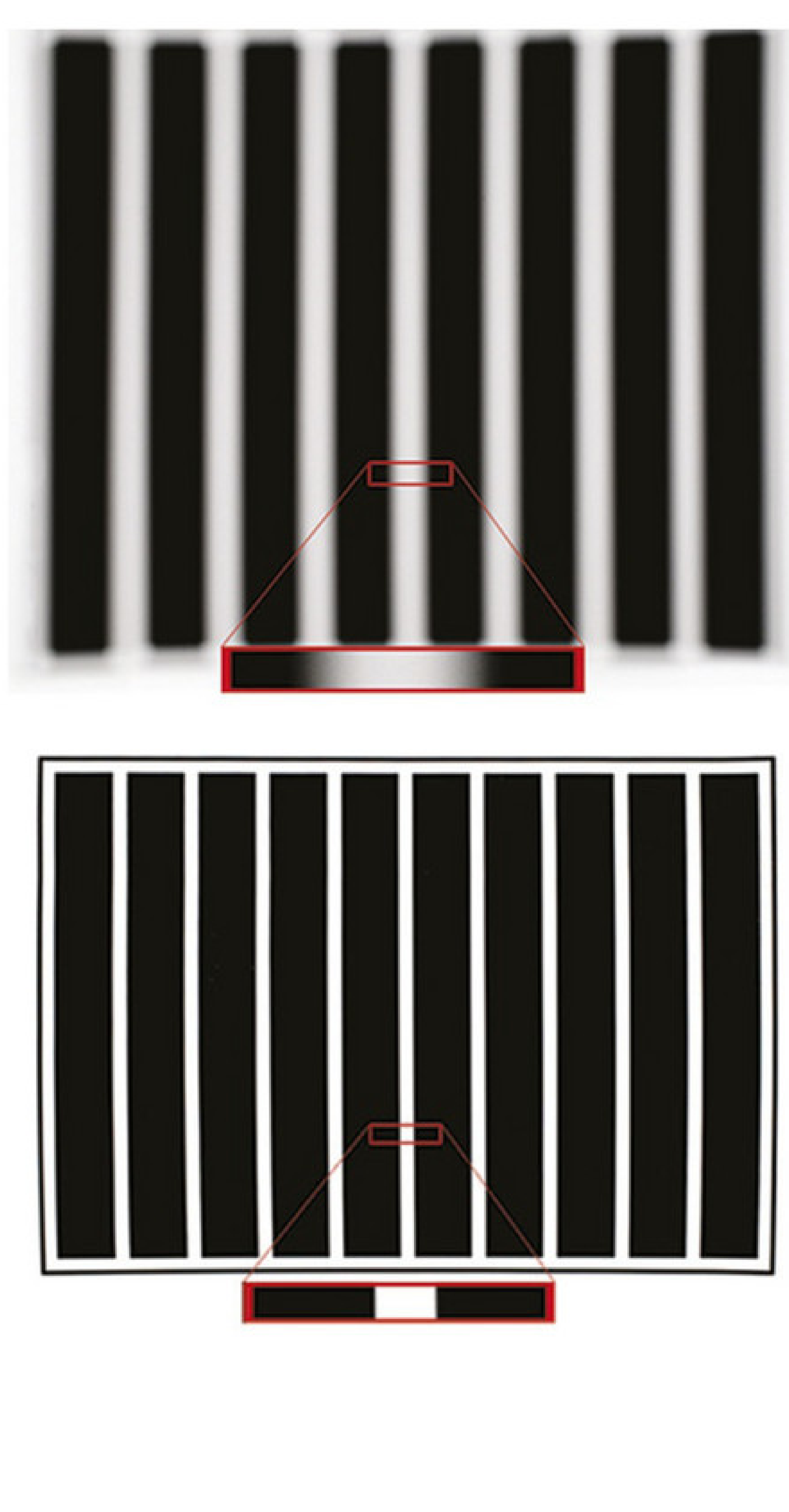


Focusing

A camera focuses in a different way to your eyes. Your eye lenses focus by changing their shape: they become more convex or flatter. A camera focuses by moving the lens: towards the image sensor chip or away from it. The closer the object gets to the lens, the further the lens moves from the sensor.

If the camera is set to autofocus, the lens will be set automatically to the right distance using a small motor. To do this, the focusing system needs information. The system can get that information in two ways: either by measuring the contrast or by determining the distance using infrared.

- When measuring contrast, the camera measures the amount of contrast between successive pixels in a horizontal row of pixels. The pixels in a blurred photo will only progress slowly from dark to light. The contrast is much greater in a sharp photo. When focusing, the



motor moves the lens back and forth to get the maximum contrast.

- The infrared system uses invisible infrared radiation. A bulb in the camera emits infrared radiation, which is reflected by the object. An infrared sensor receives the reflected signal and the computer calculates the distance to the object. After that, the motor puts the lens in the right position.

Measuring contrast can be done more quickly than infrared distance measurement using infrared light, but it does not work well when there is not much light. The entire image will be dark and there will be no strong contrasts anywhere. The infrared system always works, even if there is not much light.

DID YOU KNOW...

Moving the lens in order to focus also happens in nature: fish and frogs focus by changing the distance between the lens of the eye and the retina. If a fish wants to focus on things nearby, a special muscle pulls the lens of the eye forward to increase the distance between the lens and the retina.

Optical and digital zooming

You often want to 'bring the image closer', before you take a photo. This bringing the image nearer is called *zooming*. If the zoom factor of a camera is 10×, you can bring the image 10× closer to you. You can find two types of zoom in camera descriptions: optical zoom and digital zoom.

Optical zoom uses the optics in the camera: the system of lenses that is often simply called 'the lens' (as we have in this article too), but which is in reality made up of multiple lenses. This system makes it possible to create the zoom factor you want without having a negative effect on the resolution – and the quality – of the image.

Digital zoom is something different. It 'cuts out' part of the original image and then magnifies it using software. This affects the resolution – and therefore also the sharpness – of the image. If you cut a piece out of a digital photo and magnify it using an image processing program, you are actually doing the same thing.

All the technology in the camera makes it possible for you to concentrate on the subject: the scene that you are photographing. You decide what will be recorded and when, so you determine the composition of the image. No camera, no matter how much technology it has, can do that for you.

Exercises

1. Javier has a 5.1 MP camera. He is viewing the photos on a screen with a resolution of 1280 × 1024.
   Can this screen display the photos of Xavier's camera as sharply as they are in reality? Explain.

2. If the object in front of the lens has a lot of horizontal lines, the camera sometimes cannot focus.
   Explain why.

3. If you share a photo with others on the Internet, it is advisable to lower the resolution considerably first. The application that you are using often already does that.
   What are the two advantages of lowering the resolution?

4 Energy

Heating and insulating

People want a comfortable environment to live in. Although it may be cold outside, it has to be nice and warm inside. At the same time, people also want their energy bills to be as low as possible. This is not just to save money, it is also good for the environment.

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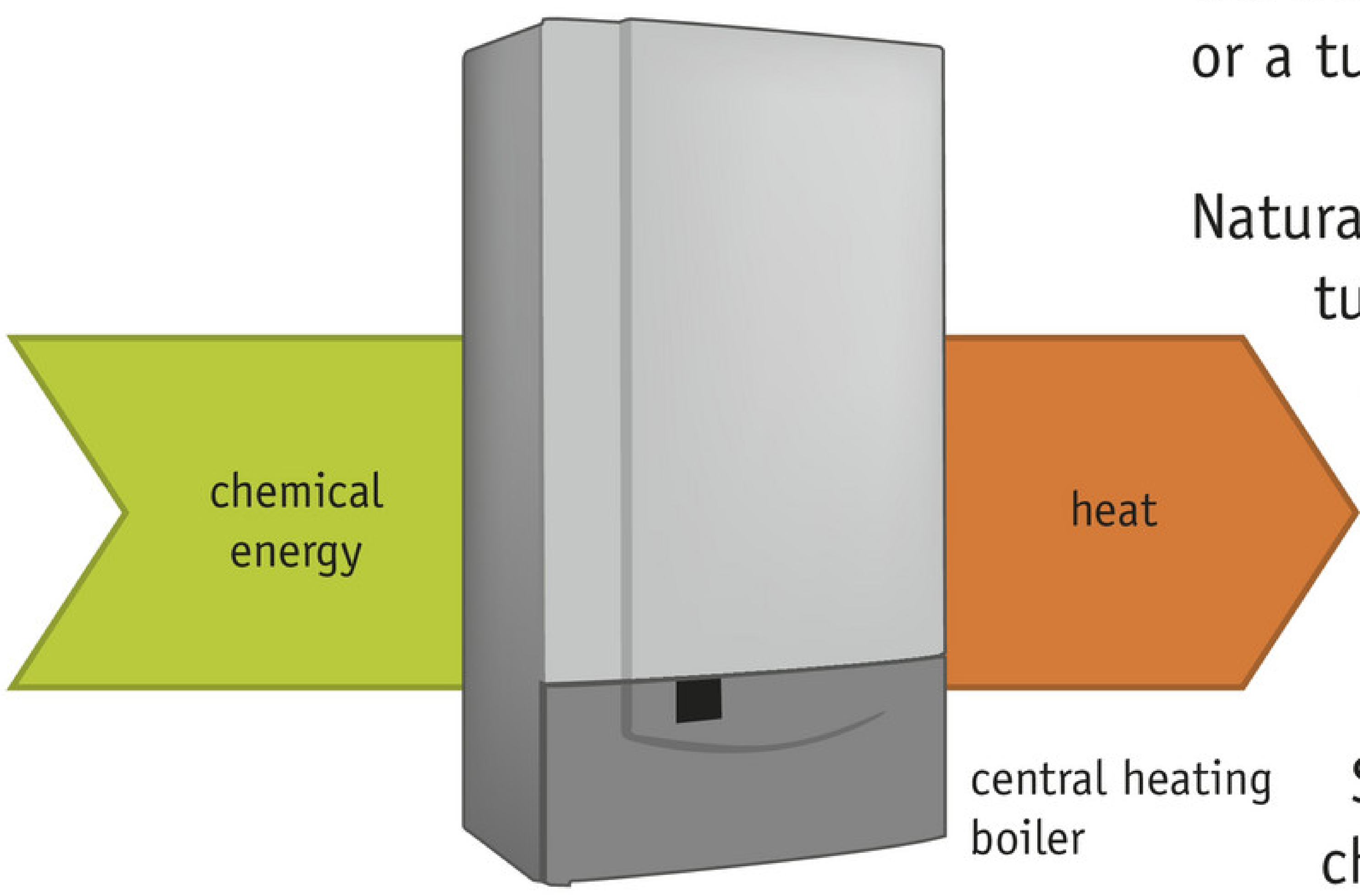
1 Heating

The piping for the natural gas network runs throughout the Netherlands. This network supplies homes and companies with chemical energy. A large part of that energy is used in heat sources, such as ovens, boilers and heaters. These provide the heat that is needed for heating systems, boiling water and preparing food.

Heat sources

If you look around your home you will find various **heat sources** such as the central heating boiler, which heats the house. Other heat sources are the stove, the oven, the kettle and perhaps a soldering iron, a hair dryer or a tumble dryer.

Natural gas gets burned in the boiler of a central heating system. This turns the **chemical energy** in the fuel into **heat**. These kinds of **energy conversions** can be represented in an **energy flow chart**, as shown in figure 1. The arrow on the left represents the energy that the heat source consumes (uses). The arrow on the right represents the energy that the heat source releases (provides).



▲ figure 1
the energy flow chart of a central heating boiler

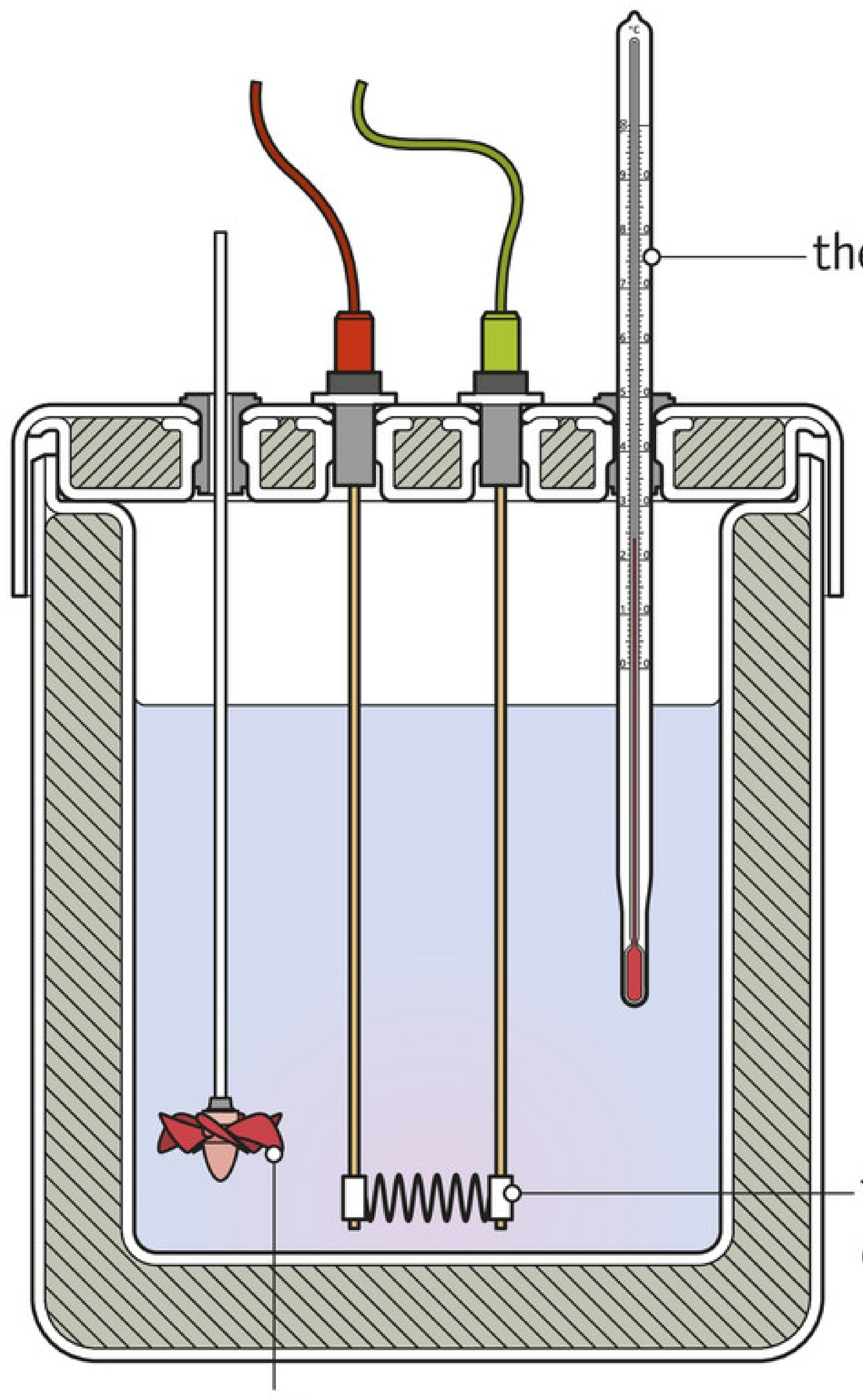
Scientists have discovered that the amount of energy does not change during an energy conversion. Certain types of energy disappear and other types of energy take their place, but the total amount of energy remains the same. That is why the left and right arrows in an energy flow chart are the same width, that shows that nothing gets added or subtracted from the total.

Heat and temperature

Most of the heat sources that you will find at home use electrical energy. Take the electric kettle that you use for boiling water for a cup of tea, for instance (figure 2). The electrical energy used by that heat source is converted completely into heat, each joule of electrical energy used provides one joule of heat.

▲ figure 2
boiling water for a cup of tea

When you heat water in an electric kettle, the temperature of the water increases from about 20 °C to 100 °C in just a couple of minutes. The increasing temperature means that the average speed of the water molecules increases. The heat absorbed by the water is used to make the water molecules move faster, that requires energy. In just the same way, you have to pedal a little harder to get your bicycle up to speed.



▲ **figure 3**
cross-section through a calorimeter

Once the water reaches a temperature of 100 °C, it starts to boil. The heat absorbed by the water is then used to move the water molecules away from each other. This creates bubbles of water vapour everywhere in the liquid. The temperature of the water will not increase any further, though, and it stays at 100 °C. Most electric kettles turn themselves off at this point.

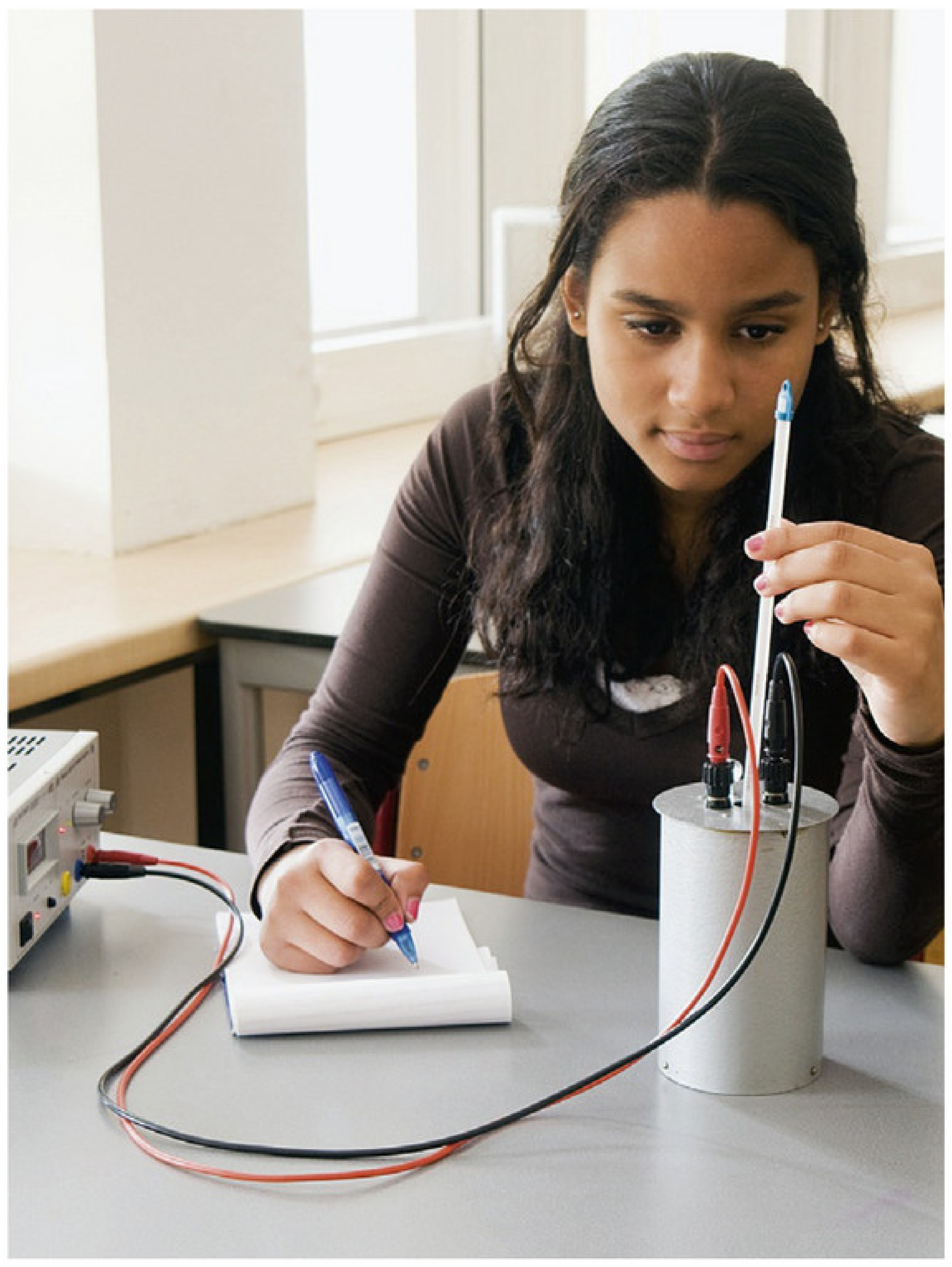
The more water you put in the electric kettle, the longer it takes before the water boils. This is because there are more water molecules whose average speed has to be increased. More heat (energy) is needed and that means the electric kettle – which puts out energy at a steady rate – takes longer to do the heating.

Experiments with a calorimeter

You can measure how much heat is required to heat a certain amount of water using a **calorimeter**. Figure 3 shows a cross-section of a calorimeter. The water in the beaker is heated up by an immersion coil, a heating element that converts electrical energy into heat. Because the beaker is well-insulated, almost all of the heat generated is absorbed by the water.

Worked example 1
Anouk fills a calorimeter with 100 g water and heats it with a 12 W immersion heater (figure 4). After 12 minutes, the temperature of the water increased from 19 °C to 39 °C.
Calculate how much heat the immersion coil generated.

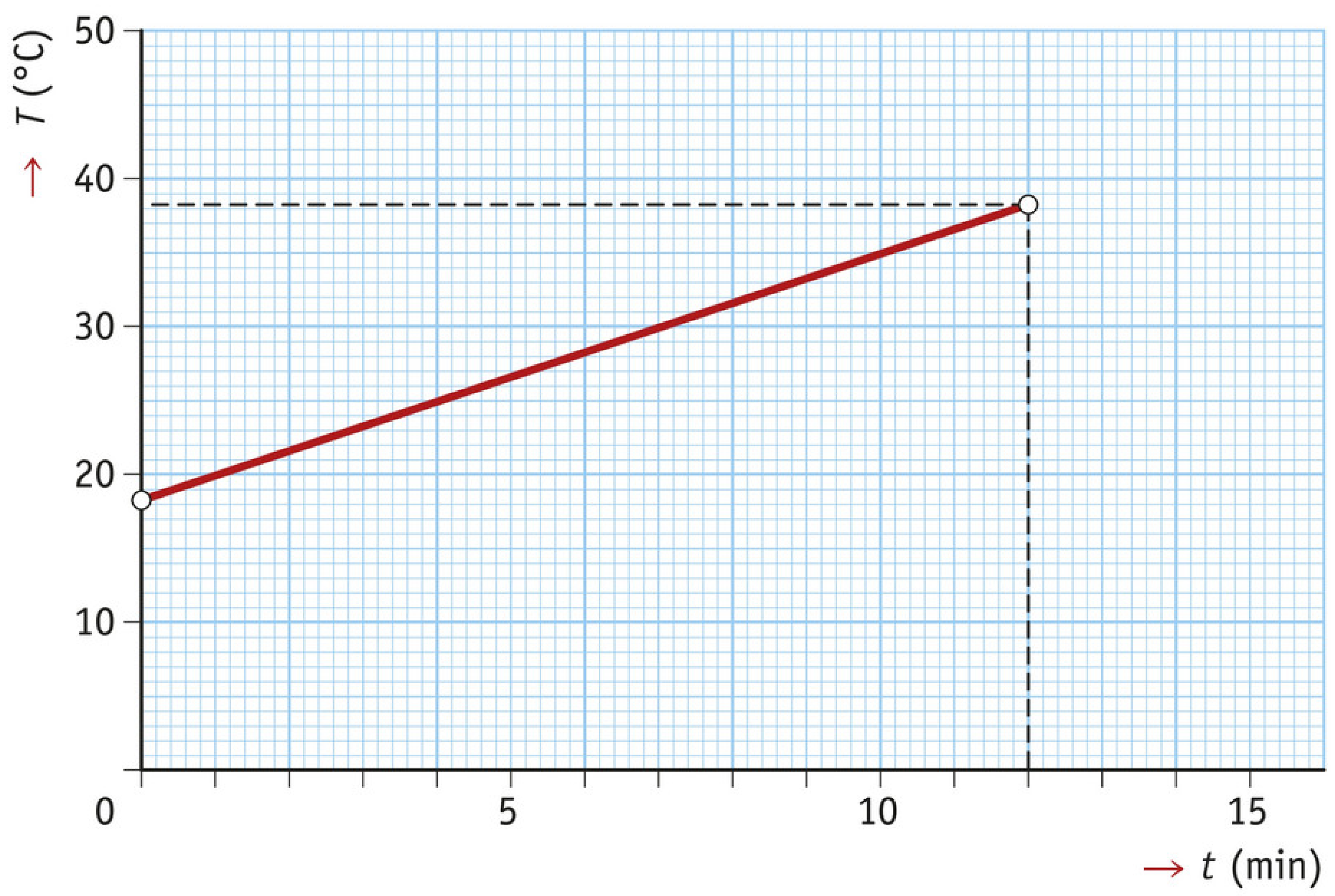
data	t = 12 min = 720 s
	P = 12 W
required	E = ?
working	$E = P \cdot t = 12 \times 720 = 8640$ J = 8.6 kJ



▲ **figure 4**
Anouk is doing an experiment with a calorimeter.

Anouk has therefore measured that about 8.6 kJ is required to increase the temperature of the water by 20 °C. In reality this value is a little bit too high, because some of the heat 'leaks' out. Precise experiments have shown that you need 4.2 J of heat to warm 1 g of water by 1 °C. It does not matter whether the temperature is being raised from 11 0 °C to 12 °C or from 78 °C to 79 °C (figure 5).

The amount of heat required to increase the temperature of 1 g of any given substance by 1 °C is called the **specific heat** of that substance. The specific heat of water is 4.2 J/g·°C. The letter c is used as the symbol for specific heat. You can also write the previous sentence like this: c_{water} = 4.2 J/g·°C. The specific heat is a property of a substance, every substance has its own specific heat.



▶ **figure 5**
The temperature increases steadily during heating: the same amount of heat is needed for each degree that the temperature rises.

Calculations with specific heat Experiments 1 and 2

The definition of specific heat yields the following formula:

$Q = c \cdot m \cdot \Delta T$

You can use this formula to calculate how much heat is required to heat a quantity of a substance to a certain temperature. As you can see, three factors determine Q, the amount of heat needed:

- the type of substance: every substance has its own specific heat c;
- the quantity of the substance: the mass m measures this;
- the desired temperature increase: $\Delta T = T_{end} - T_{init}$.

If you give c in J/g·°C, m in g and ΔT in °C, you will get Q in J.

Worked example 2
An electric kettle (1600 W) heats 1.5 L water from 20 °C to 100 °C. Calculate how many minutes it takes. Assume that all electrical energy is used to heat the water.

1 Calculate how much heat the electric kettle has to generate.
The mass of 1.5 L water is roughly $1.5 \cdot 10^3$ g. The water temperature increases by 80 °C.

data $c = 4.2$ J/g·°C
$m = 1.5 \cdot 10^3$ g
$\Delta T = 80$ °C

required $Q = ?$

working $Q = c \cdot m \cdot \Delta T = 4.2 \times 1.5 \cdot 10^3 \times 80$
$= 5.04 \cdot 10^5$ J of heat

2 Calculate the time required.
The electric kettle has to turn $5.04 \cdot 10^5$ J of electrical energy into $5.04 \cdot 10^5$ J of heat.

data $E = 5.04 \cdot 10^5$ J
$P = 1600$ W

required $t = ?$

working $E = P \cdot t$
$5.04 \cdot 10^5 = 1600 \times t$

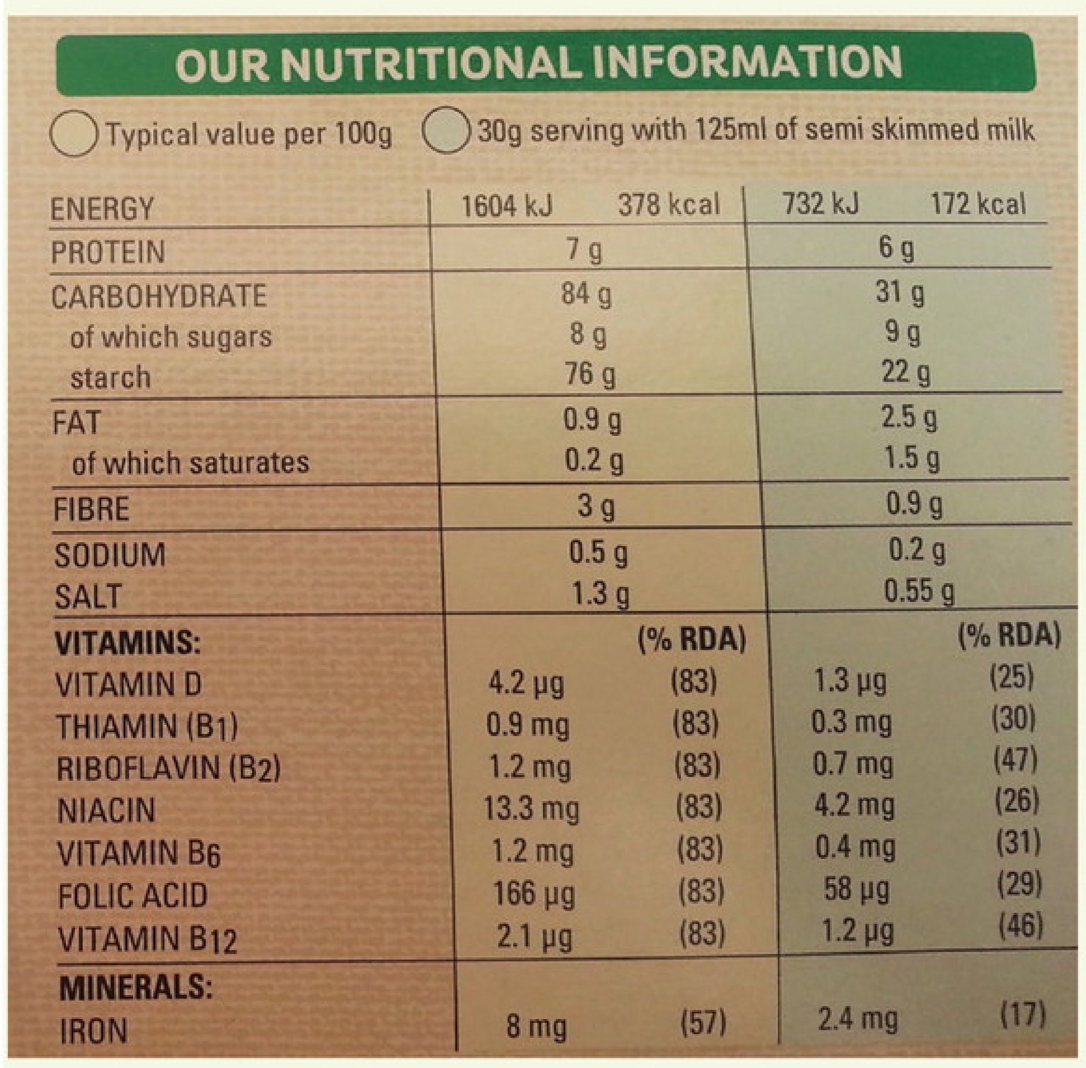
$$t = \frac{5.0 \cdot 10^5}{1600} = \text{(about) } 315 \text{ sec} = 5 \text{ min and } 15 \text{ s}$$

Plus Joules and calories

For a long time, scientists did not realise that electrical energy and heat are both types of energy. There used to be a separate unit for heat, the calorie (cal), defined as the amount of heat required to raise the temperature of 1 gram water by 1 degree Celsius. This definition is very useful if you are measuring with a calorimeter.

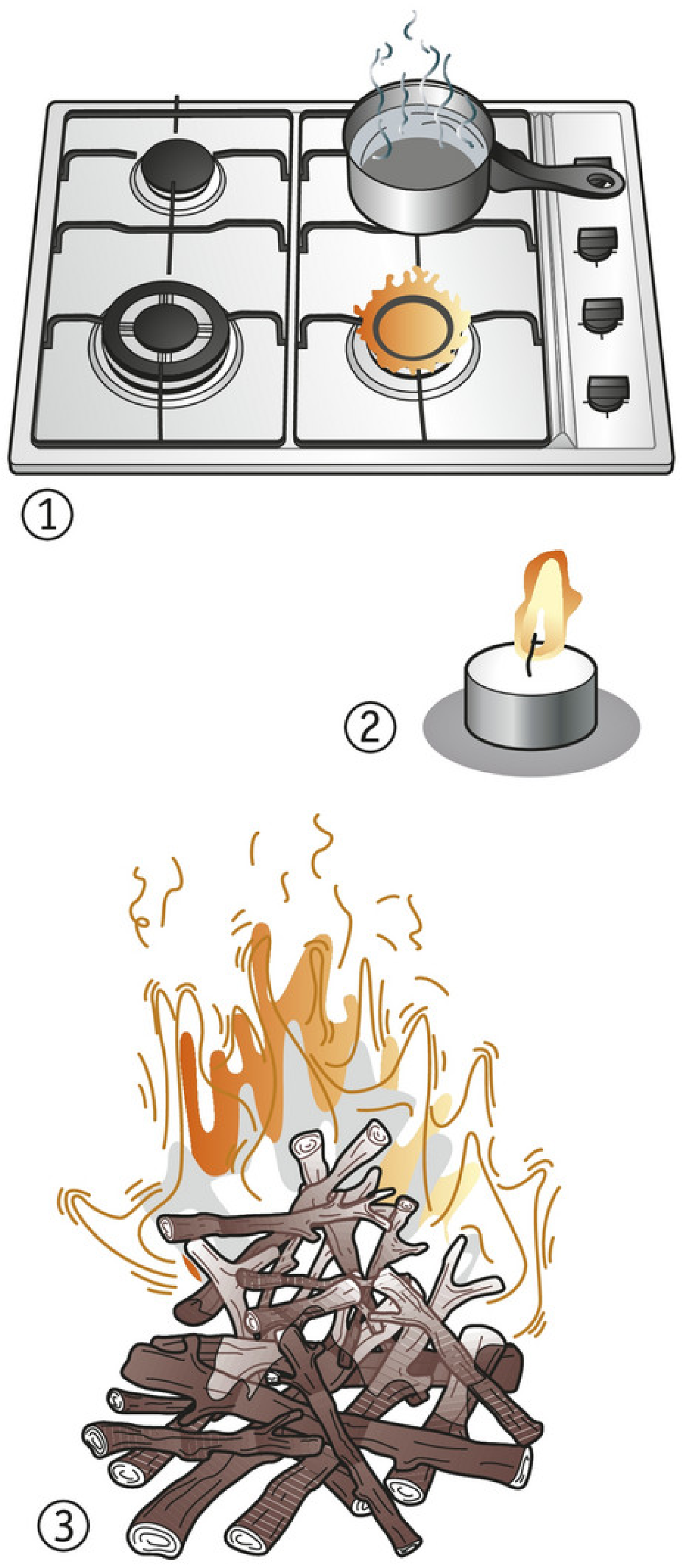
Precise experiments showed that producing 1 cal of heat always required the same amount of electrical energy: 4.184 J or roughly 4.2 J. These sorts of experiments convinced scientists that heat is a type of energy that can be measured in joules just like electrical energy. The advantage of having a single unit for energy is that you do not have to convert one unit to the other anymore.

It took about a hundred years before this idea was put in practice, but since 1 January 1978 the joule is the only lawfully acknowledged unit for energy (including heat) in the Netherlands. From that moment on, the calorie could no longer be used. An exception was made for the packaging of foods; these list the energy value in kJ as well as kcal (figure 6).



▲ **figure 6**
Food labels list the energy value in kJ as well as kcal.

Exercises



▲ **figure 7**
three heat sources

1 Answer the questions below.
- **a** Which two types of energy do the heat sources you use at home run on?
- **b** What energy conversion takes place in the central heating boiler?
- **c** Why are the arrows in an energy flow chart the same width on the left and the right?
- **d** What does it mean when we say that the 'specific heat of water is 4.2 J/g·°C'?

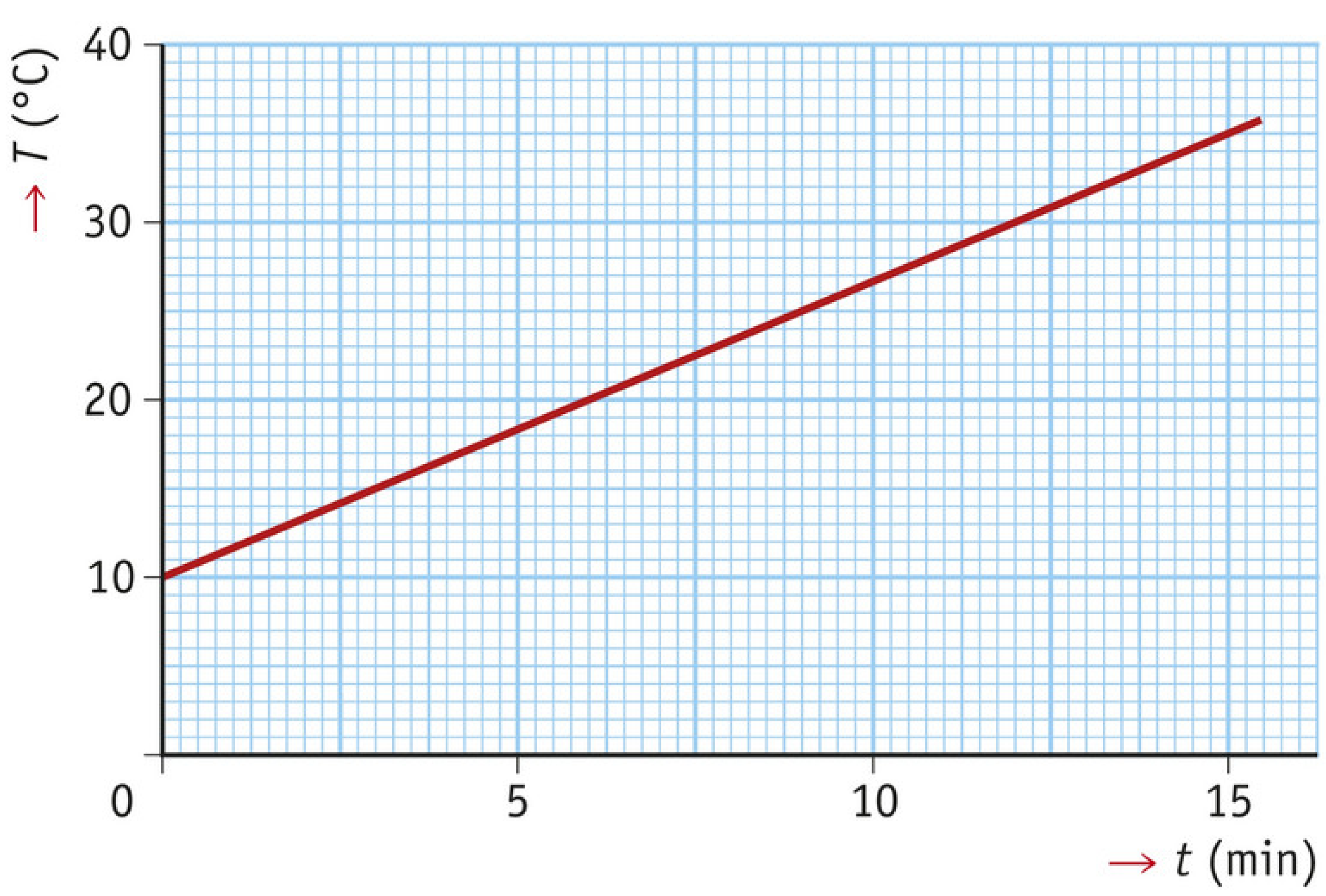
2 Look at the illustration of the calorimeter in figure 3.
Explain:
- **a** how the water in the calorimeter gets heated.
- **b** how to prevent heat 'leaking' from the calorimeter.
- **c** what to do to spread the heat as evenly as possible.
- **d** how to measure the temperature of the water in the calorimeter.

3 Figure 7 shows you three heat sources.
- **a** Write down which fuel is burned in each heat source.
- **b** What do you call the type of energy that these heat sources use?

4 You need worksheet 4-1 for this exercise.
- **a** Complete the energy flow chart on the worksheet.
- **b** Label the arrows with the type of energy:
  - that the electric kettle absorbs.
  - that the electric kettle releases.

5 You need worksheet 4-2 for this exercise.
Eddie heats 100 mL water with a Bunsen burner. He measures the temperature every 30 s. A graph showing his measurement results has been printed on the worksheet.
After that, Eddie heats 150 mL water. The flame of the Bunsen burner is equally large and just as hot as the first time. Again he measures the temperature every 30 s.
Sketch the graph for this experiment on the worksheet (with 150 mL water).

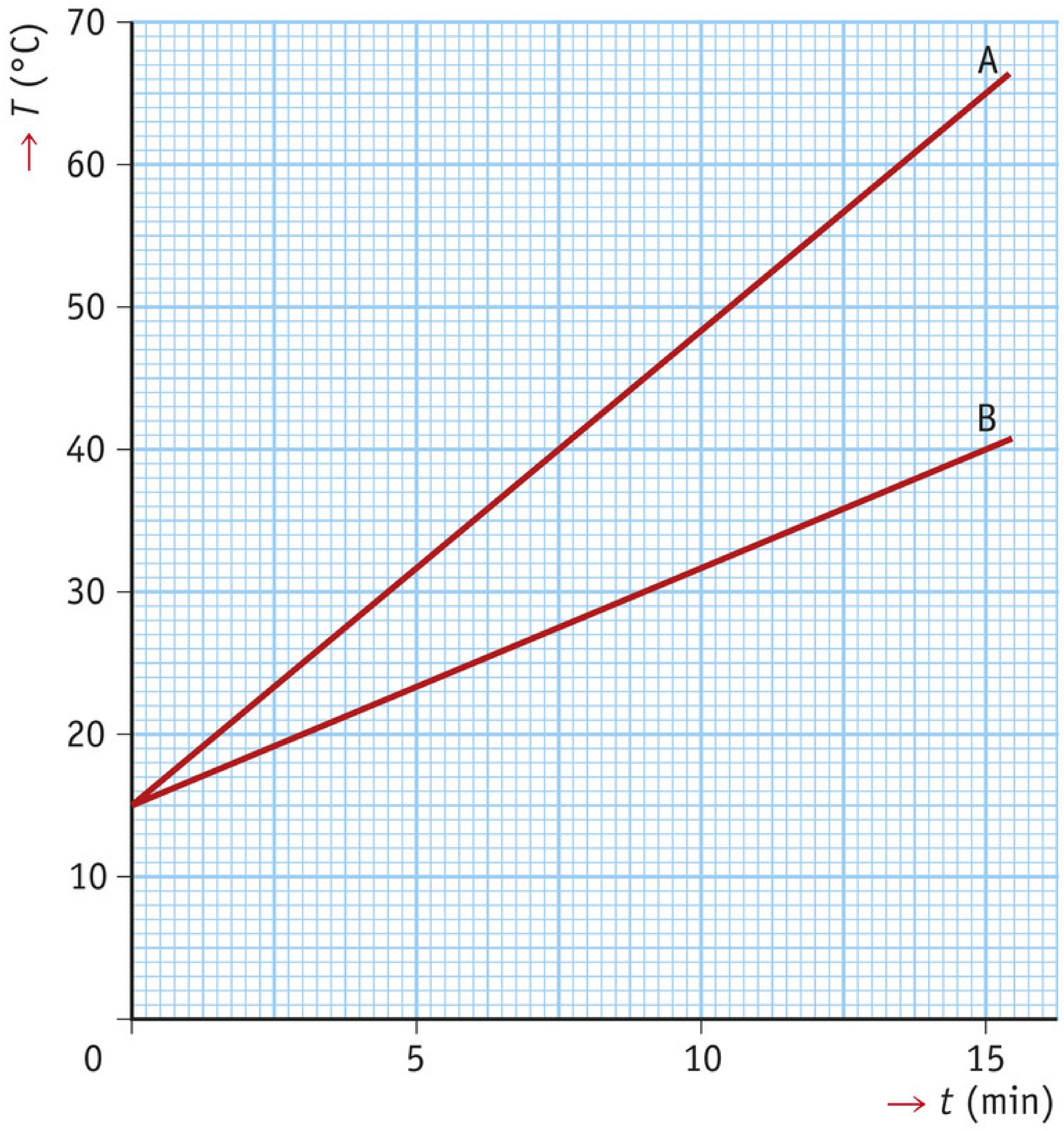
▼ **figure 8**
Lisa's graph



6 Lisa has heated 150 g water in a calorimeter. You can see the graph of her experiment in figure 8.
- **a** See 'Skills 3' at the back of the book.
  Calculate how much heat the water absorbs in 15 minutes.

  If you need more practice, go to the V-trainer.

- **b** Calculate the power of the heating element.
- **c** Your results for b will be a little bit too low compared to the actual power.
  Why is that?



▲ **figure 9**
John's graph

7 Joseph first heated 100 g of liquid A in a calorimeter and then 100 g of liquid B. He used the same 12 W heating element in both cases. You can see the graph of the two experiments in figure 9.
- **a** Which liquid has the greater specific heat? How can you see that?
- **b** Which of these two liquids could be water? Show how you got your answer.

***8** Joanie fills the electric kettle in figure 10 full with water at 20 °C. She then turns on the appliance. Calculate how long it will take (at least) until the water boils.

***9** Ellie makes 1.5 L tea at the campsite with a Bunsen burner. She heats the water from 20 °C to 100 °C. Unfortunately, 50% of the heat produced flows past the pan and is lost. The fuel produces 46 kJ heat per gram.
Calculate how many grams of fuel she uses.

Plus Joules and calories

10 The theoretical part of the text says the following about the definition of the calorie: "This definition is very useful if you are measuring with a calorimeter."
Explain why this definition is so useful (think up your own reason).

***11** Search the Internet for information about the energy value of food.
- **a** What is the energy value of:
  - carbohydrates?
  - fats?
  - proteins?
  - alcohol?
- **b** What units are used to express the energy value?
- **c** How can you convert one unit to the other?

ELECTRIC KETTLE
- volume 1.7 litres
- 2200 W
- removable jug
- boil-dry cut-out
- water level indicator
- attractive design
- one-year guarantee

◀ **figure 10**
Does it boil quickly or slowly?

2 Energy sources

▲ figure 11
a coal-fired electricity station on the Maasvlakte near Rotterdam

We use all kinds of energy sources in the Netherlands, some on a large scale (such as natural gas), others on a more modest scale (such as geothermal energy). Each energy source has its benefits and disadvantages.

What is an energy source?

Anything that can provide a usable form of energy is called an **energy source**. An energy source stores some type of energy that can be used by an energy converter:
- A central heating boiler can use the chemical energy of natural gas.
- A solar cell can use the radiant energy of sunlight.
- A windmill can use the kinetic energy of flowing air.

Natural gas, sunlight and wind are examples of energy sources: they deliver a usable type of energy.

Five energy sources

Five energy sources that are used in the Netherlands are listed below. The list is incomplete and the energy sources are not all equally important. In the future, 'alternative' energy sources will probably become more important, and fossil fuels will become less important.

Fossil fuels

Fossil fuels such as petroleum, natural gas and coal provide chemical energy. Petroleum products are used on a large scale in the shipping industry (fuel oil), road transport (petrol and diesel) and aviation (kerosene). Natural gas is used to heat homes and other buildings. Several power plants in the Netherlands use coal (figure 11).

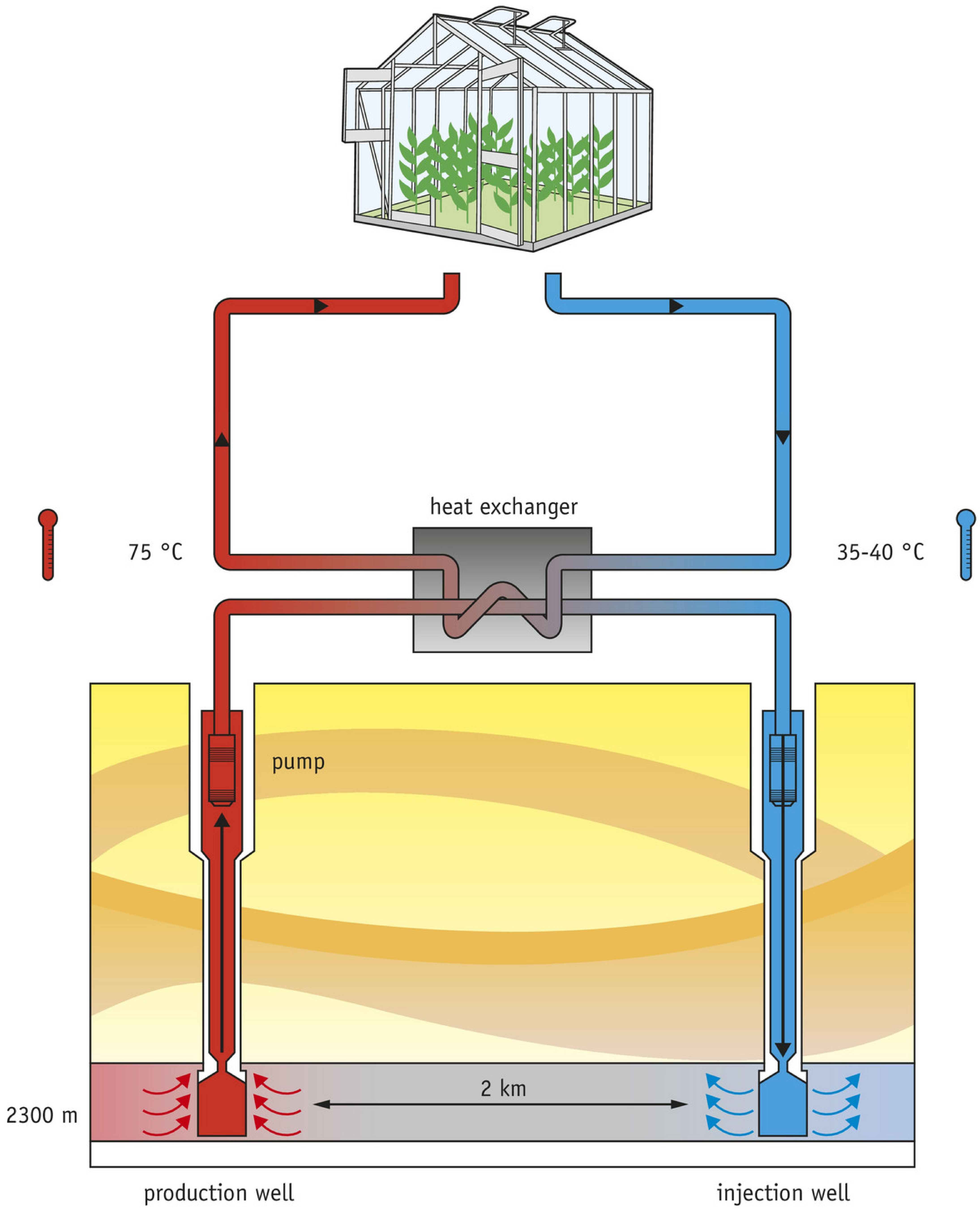
Biomass

Biomass is material that originates from plants and animals. This can range from pruning and waste wood, plant remains and cow and chicken manure to crops such as rapeseed and maize. Some types of biomass can be burned directly. Manure needs to be fermented in a biogas plant. This produces a gaseous product called biogas. The composition of biogas is very similar to natural gas and it can be used for the same purposes.

▲ figure 12
This is how solar panels are fitted.

Sunlight
Sunlight is a source of **radiant energy**. This radiant energy can be converted into heat by a **solar collector** and can then be used to heat water. You can also convert the radiant energy of sunlight into electrical energy using **solar cells**.
More and more people are getting panels with solar cells installed on the roofs of their house or shed (figure 12).

Geothermal heat
The temperature increases the deeper you get in the Earth. It is possible to get the heat from the deeper layers of the Earth's crust up to the surface. Two wells are used to extract this **geothermal heat** (figure 13). The first well is used to pump hot water up from deep underground. This water is passed through a **heat exchanger** where it releases some of its heat. The cooler water is then pumped back into the Earth through the second well.



▶ figure 13
Geothermal energy is used for heating greenhouses, for example.

▲ figure 14
There are often protests against plans for wind farms.

Wind
There used to be over 9000 windmills in the Netherlands. Nowadays, wind has become an important energy source again. More and more large wind turbines are starting to dot the landscape. A wind turbine powers a generator that is built into the mill. This converts the **kinetic energy** of the wind into electrical energy.

Benefits and disadvantages

Each energy source has its benefits and disadvantages. When you compare energy sources, you should pay attention to the following four points:

How much do you have to pay for the energy?
At the moment, electricity generated from the wind is more expensive than electricity generated by fossil fuels. This could change if oil and gas prices rise sharply.

Could the energy source eventually become depleted?
Our fossil fuels reserves are limited. Someday they will be exhausted. But the wind will always keep blowing, it will never 'run out'.

Is the energy source always available, or only every now and then?
A power plant running on natural gas can deliver electrical energy twenty-four hours a day. But a wind turbine doesn't move if there is no wind.

What are the consequences for the environment?
Burning fuels create waste substances that are often damaging to the environment. Wind turbines have other disadvantages, such as skyline pollution and noise disturbance (figure 14).

Plus How 'green' is biomass?

Biomass is often referred to as a 'renewable energy source'. This means that you can replenish the biomass reserves again and again. If you cut down trees to use as wood for fuel, you can then plant new trees which will grow by themselves. If you manage a forest sensibly, and if it's big enough, you will never have to run out of wood for fuel (figure 15).

▲ figure 15
a stack of wood as fuel for the winter

Even so, it doesn't necessarily mean that using biomass is good for the environment. That depends on how the biomass is produced, transported, modified and used. The cultivation of some 'energy crops' requires a lot of pesticides – not a positive thing for the environment. That's why the benefits and disadvantages of different kinds of biomass are the subject of so much debate.

Exercises

12 Answer the questions below.
- **a** Which fossil fuels are used a lot in the Netherlands?
- **b** How can manure be used as an energy source?
- **c** What energy conversion takes place in a solar collector?
- **d** What disadvantages do modern wind turbines have for the environment?

13 Copy table 1 and fill in the missing data.

▼ **table 1** five sources of energy that are used in the Netherlands

energy source	type of energy	energy converter
		central heating boiler
biomass		
sunlight		
		heat exchanger
	kinetic energy	

▲ **figure 16**
an important source of energy during the Dutch Golden Age

14 The painting in figure 16 was made in the Dutch Golden Age.
- **a** What energy source does the ship use?
- **b** What type of energy does this energy source provide?

15 Four energy sources are shown below:
- geothermal heat
- wind power
- fossil fuels
- solar energy

Each of these energy sources has benefits and disadvantages.
- **a** Which energy source is clean to use, but causes noise disturbance and skyline pollution?
- **b** Which energy source is still available 24 hours a day at the moment, but will eventually completely run out?
- **c** Which energy source will never run out, but provides much less energy in the winter than in the summer?
- **d** Which energy source can provide clean heat for horticulture, but requires large investments?

16 Read the newspaper article in figure 17.
- **a** The article states that the solar cooker preserves the environment. Explain what exactly gets 'preserved'.
- **b** People in Africa sometimes have to walk for hours to get firewood. None can be found close to their villages anymore. What might be the reason?
- **c** The article lists various benefits of the solar cooker. Think up a disadvantage of the solar cooker yourself.
- **d** The solar cooker has a double-glazed lid. Why did the inventor choose to use double glazing instead of single glazing?

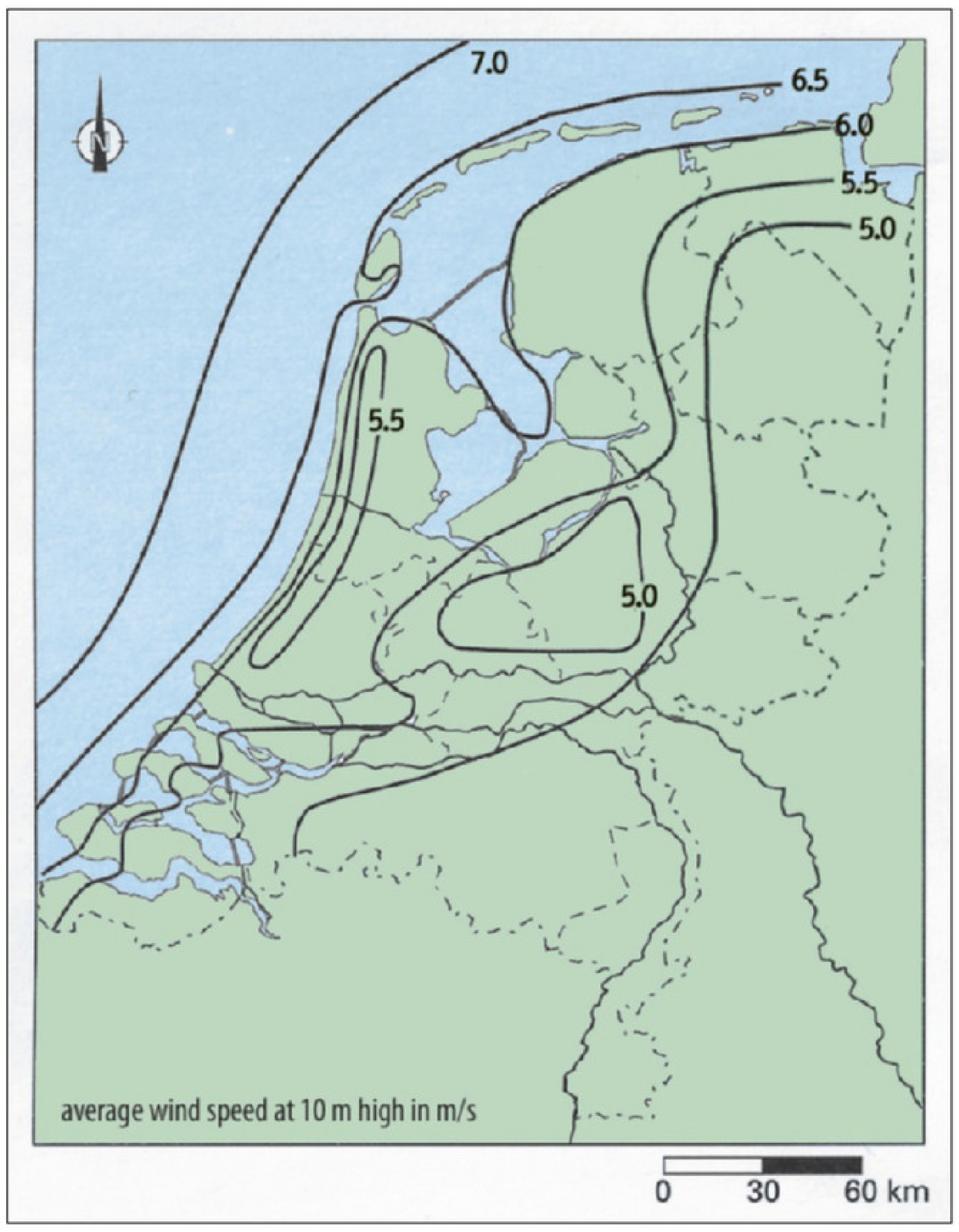
The Solar Cooker

The Solar Cooker is as simple as it is unique. It was invented by an 84-year-old inventor from Ermelo called Jan Dierkx. Dierkx knocked together a box containing a light-weight metal basin and a double-glazed lid. Even the Dutch summer sun is enough to cook food in it slowly, let alone in sun-drenched Africa. The oven is cheap, robust enough for the African climate and can achieve high temperatures so that harmful bacteria are killed. It also has the benefit of not harming the environment. A family no longer has to spend hours every day collecting wood to burn. Each solar cooker saves twenty trees a year.

▶ **figure 17** solar energy for Africa

17 It is often useful to be able to store energy, to allow for fluctuations in supply.
Where and in what form do such stocks of energy get stored:
- **a** by an oil company that is making allowances for an oil crisis?
- **b** by a potato plant that produces a lot of spare energy during the summer?
- **c** by a bear that prepares itself in autumn for the coming winter?

18 The Netherlands is next to the North Sea. Because of this, the average wind speed in the country is quite high. That is why the Netherlands is so suitable for energy generation with wind turbines. The average wind speeds are shown in figure 18. The lines in this diagram connect places with the same average wind speed.
- **a** Why is the average wind speed lower inland than in the coastal areas?
- **b** Wind turbines can also be placed in the North Sea now, 10 km or more from the coast.
  What benefits could this have? State two.
- **c** Also state a disadvantage of placing wind turbines in the sea (think up one yourself).



▶ **figure 18**
This shows how much wind there is on average in the Netherlands.

19 A power company wants to replace a power plant with a capacity of 800 MW with windmills. A windmill about 100 m high provides 3.0 MW on average.
- **a** Calculate how many windmills would be needed.
- **b** The windmills are placed along the coast. The length of the coastline of the Netherlands is 451 km.
  Calculate the distance between the windmills.
- **c** Give one benefit and one disadvantage of this plan.

***20** Search the Internet for information about one of the following energy sources: natural gas, geothermal heat, biomass, tides, coal, wind, sunlight.
Describe in a short essay (a maximum of two A4 pages):
- **a** how the energy source can be used.
- **b** what benefits the energy source offers.
- **c** which disadvantages and limitations the energy source has.

Plus How 'green' is biomass?

21 Biomass is referred to as a renewable energy source.
- **a** Explain what is meant by 'renewable'.
- **b** List three other renewable energy sources.

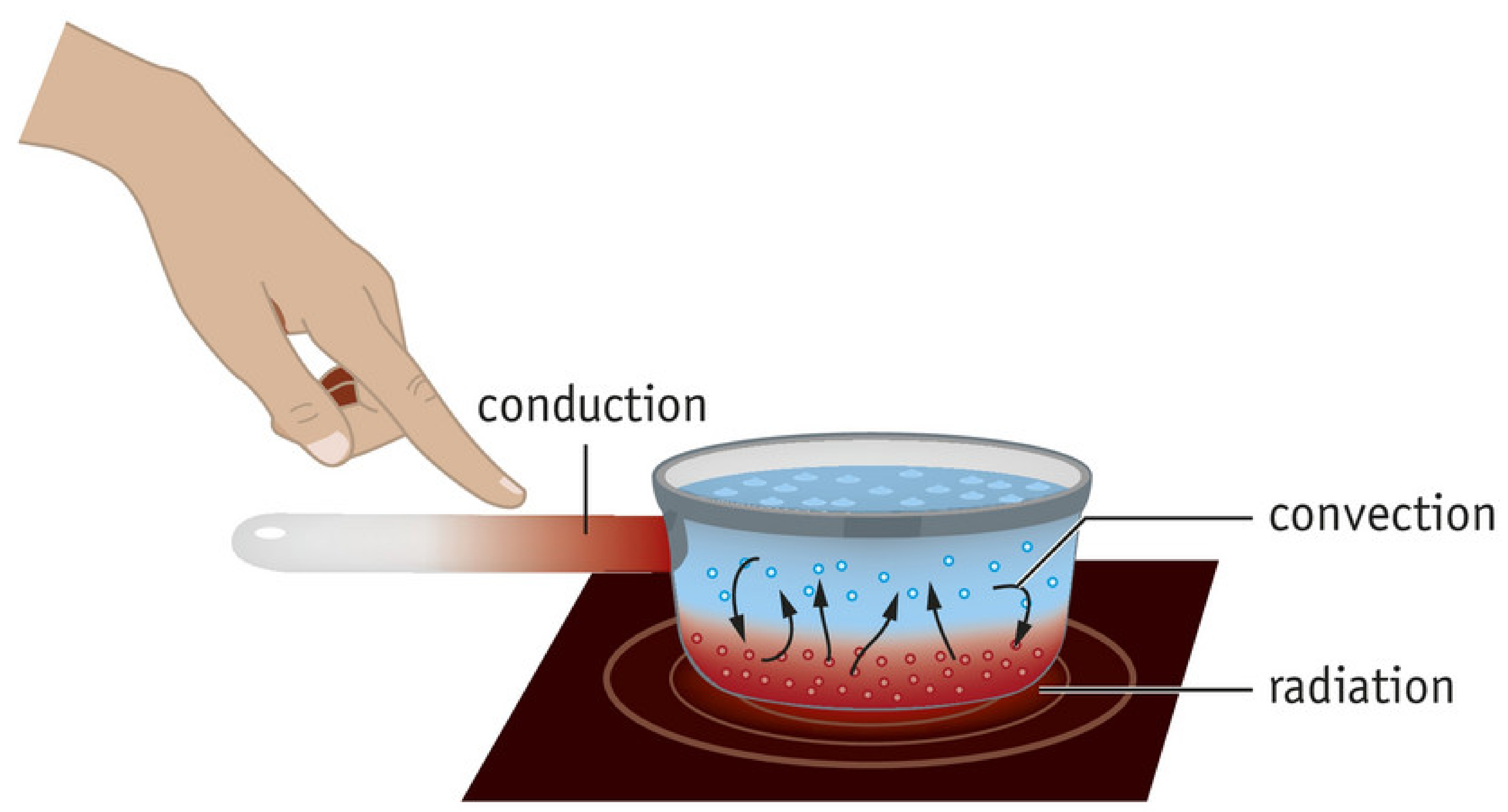
***22** Search the Internet for information about biomass.
- **a** What can be used (burned) as biomass? Make a list.
- **b** Which crops are cultivated on a large scale as 'energy crops'?
- **c** Why is a distinction made between 'good' and 'bad' biomass?
- **d** Give an example of 'bad' biomass and explain why it is bad.

3 Insulation

If you turn the central heating on in a cold house, the temperature will rise at first. But after a while the temperature will not change anymore, even though the central heating boiler still comes on regularly. This is because the same amount of heat escapes to the outside as the boiler is generating. You can restrict this heat loss by insulating properly.

Heat loss Experiments 3 and 4

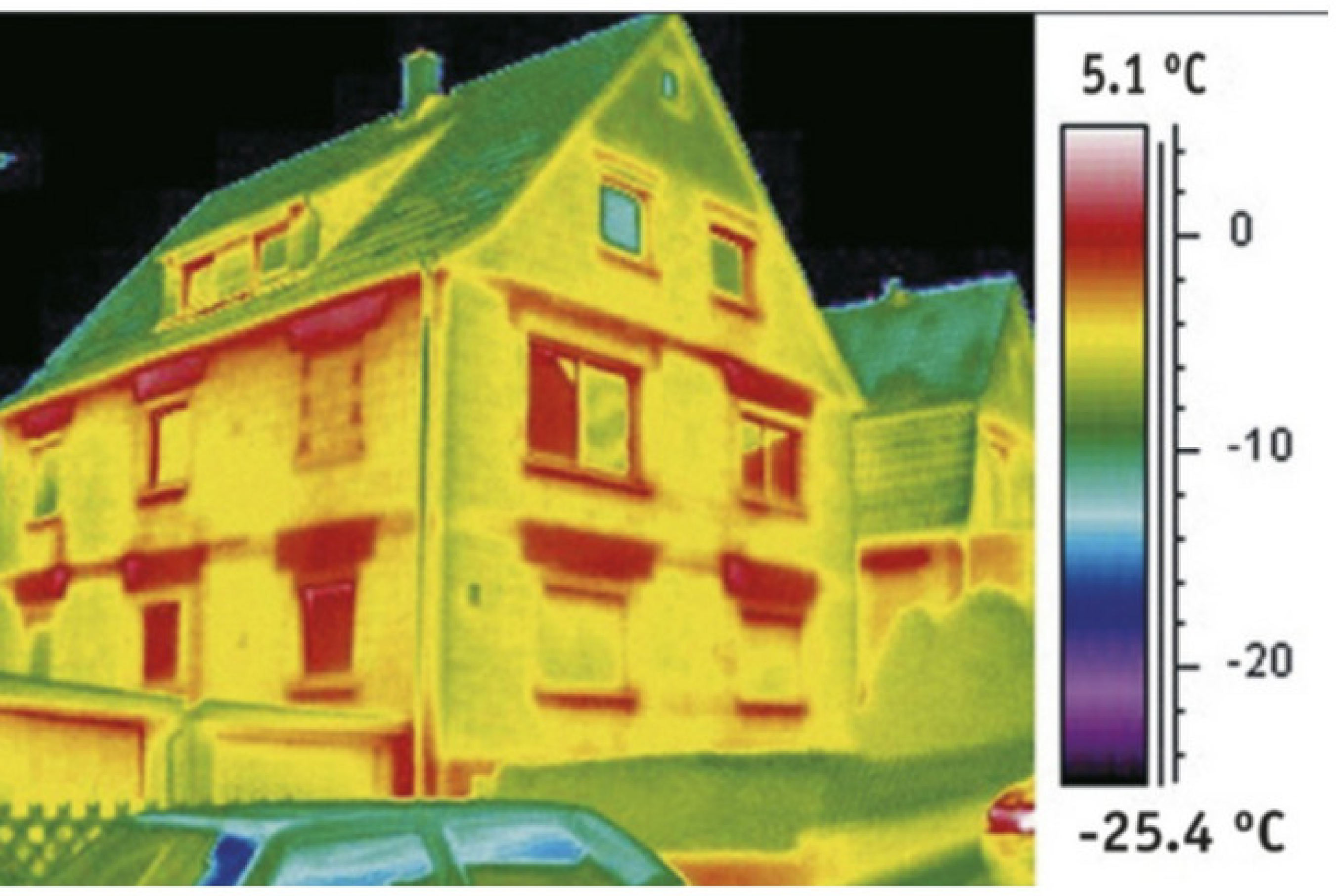
If the temperature indoors is higher than the temperature outside, heat will constantly be escaping from the house. This happens most quickly when the wind is blowing, because the warmer air from inside and around the house gets blown away. But heat leaks away constantly, even when there is no wind. This happens in three ways: through **conduction**, **convection** and **radiation** (figure 19).



▶ **figure 19**
conduction, convection and radiation in the kitchen

Conduction
Convection is the flow that occurs in a liquid or gas if you heat it in one place. This is because the molecules of the substance are continually colliding with one another. As they do so, they pass their kinetic energy from one to the next. This is how the heat spreads from indoors (where the temperature is higher) to outside (where the temperature is lower).

Convection
A convection is a flow that can occur in a liquid or gas if you heat it in one place. You can see that for instance in the air indoors. The air near the radiators heats up and expands as the density decreases. This makes the warm air rise through the surrounding colder air, carrying the heat with it.



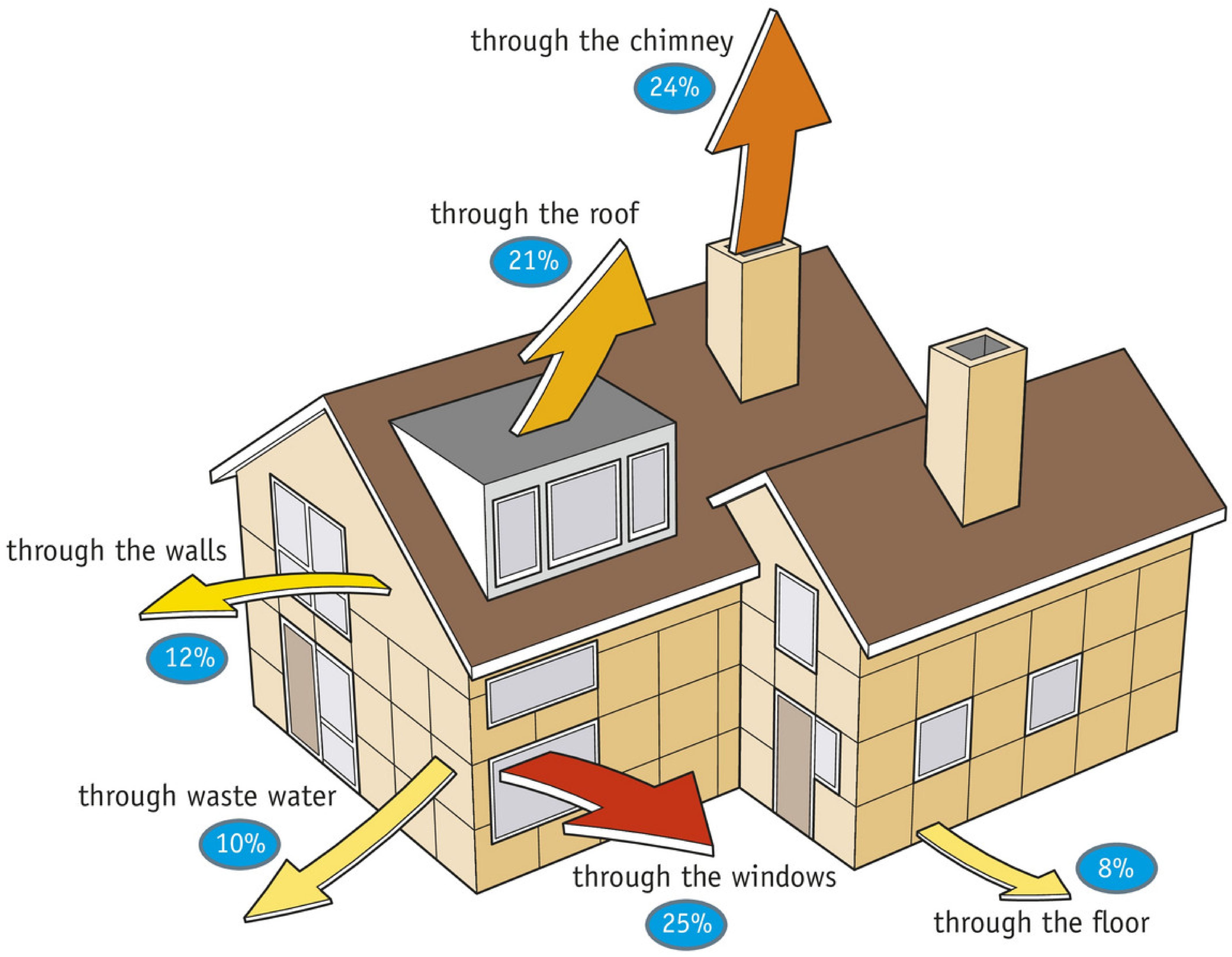
▲ figure 20
A thermogram makes it possible to see the infrared radiation being emitted by a house.

Radiation
Everything around you – including your own body – emits radiation, tiny packets of radiant energy that can travel freely through air or even space. The higher the temperature of the object, the more radiation it emits. This is why a warm house loses more heat in the winter than it receives from the colder air outside it (figure 20).

Conduction, convection and radiation are very different processes. But all three have the same effect, the heat 'spreads' from the area where it is hotter to areas where it is colder. As a result, hot objects are constantly losing heat. In practice you have then lost that heat for good, the energy has spread over such a large area that it cannot be used for any practical purposes.

Restricting heat loss

The heat that escapes from a house must be replaced straight away (figure 21). Otherwise the temperature will continue to decrease until it is just as cold as it is outside. That is why the central heating boiler has to be on constantly during cold weather to maintain the temperature of the house.



▶ figure 21
How heat escapes from a typical house.

If the house has not been insulated properly lots of heat will escape to the outside. The boiler will then have to burn a lot of fuel to replace the lost heat. You can combat heat loss by **insulating** the house. The boiler will then not have to generate as much heat to provide a comfortable temperature.

▲ figure 22
Insulation materials consist largely of air.

Heat transfer through a wall

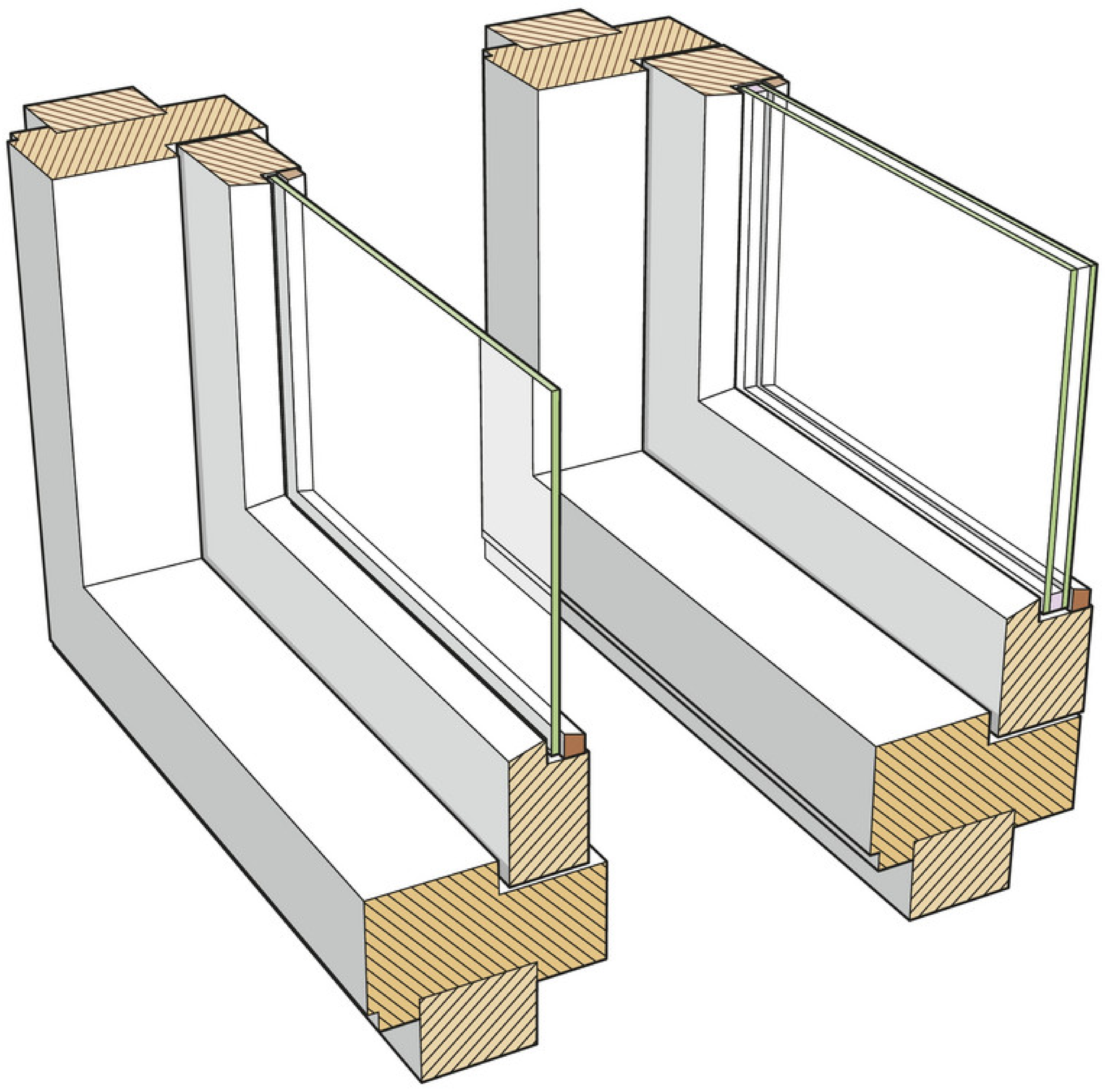
The walls of a house are often made of brick. This building material is a relatively good heat conductor. That means that quite a lot of heat can escape outside through the walls.

How much heat disappears outside in a given time depends on:
- the difference in temperature between inside and outside: the smaller the difference, the less heat escapes;
- the material the wall is made of: the more poorly it conducts heat, the less heat escapes;
- the thickness of the wall: the thicker the layer of insulating material, the less heat disappears outside through the insulation;
- the surface area of the wall: the smaller the surface area, the less heat disappears to the outside through the insulation.

You can counteract the loss of heat by placing a layer of insulating material against the wall. Roofs and floors are also often insulated this way. A layer of insulation that is 5 cm thick can cut the heat losses through a wall by a factor of four. Insulation materials are full of small spaces that contain air. Because air is a very poor conductor of heat, the heat losses are cut hugely (figure 22).

Insulating a house

There are other ways of insulating a house too. For example:
- by replacing single glazing, which lets heat through easily, with double glazing (figure 23);
- by filling the cavity wall (the gap between the inner and outer walls) with insulating material;
- by insulating roofs and floors with materials such as glass wool, rock wool, polystyrene and air cushion sheeting;
- by insulating central heating and hot water pipes where they run through colder areas such as a garage.



▶ figure 23
single glazing (left) and double glazing (right)

Worked example 3
Inez reads in a folder that you can save a lot of energy by insulating central heating pipes, about 10 m^3 of natural gas per metre of pipe per year. 1 m^3 of natural gas generates $32 \cdot 10^6$ J of heat.
Inez insulates 15 metres of central heating pipes in her home.
How much heat does that save her per year?

data	insulating 1 m pipe saves 10 m^3 natural gas per year 1 m^3 of natural gas generates $32 \cdot 10^6$ J of heat.
required	the amount of heat saved per year
working	insulating 15 metres of pipe saves $15 \times 10 = 150$ m^3 natural gas per year. That corresponds to $150 \times 32 \cdot 10^6 \approx 4.8 \cdot 10^9$ J = 4.8 GJ of heat.

Plus Energy-neutral living

An average home uses quite a lot of chemical and electrical energy. The residents soon see that when they read the meters for their annual energy bills. The electricity consumption of an average household was 3500 kWh in 2013 and the average gas consumption was 1600 m^3. That means a total energy bill of over € 1.900 (including standing charges, at 2013 prices).

▲ figure 24
an experimental house that is (almost) energy-neutral

The residents can reduce their energy bills by insulating their home properly. This will let them avoid burning too much natural gas. More and more people are also choosing to provide for part of their own energy requirements. This can be done for example by placing solar collectors or solar panels on the roof. All those measures taken together mean that the energy bill will be less.

The government wants buildings to be **energy-neutral** in the future. That means that a building – averaged out over the whole year – will generate as much energy as it consumes (figure 24). It is allowed to use energy 'from outside', as long as it gives back the same amount. A house owner could for example compensate for his consumption of natural gas by delivering 'solar power' to the electricity grid.

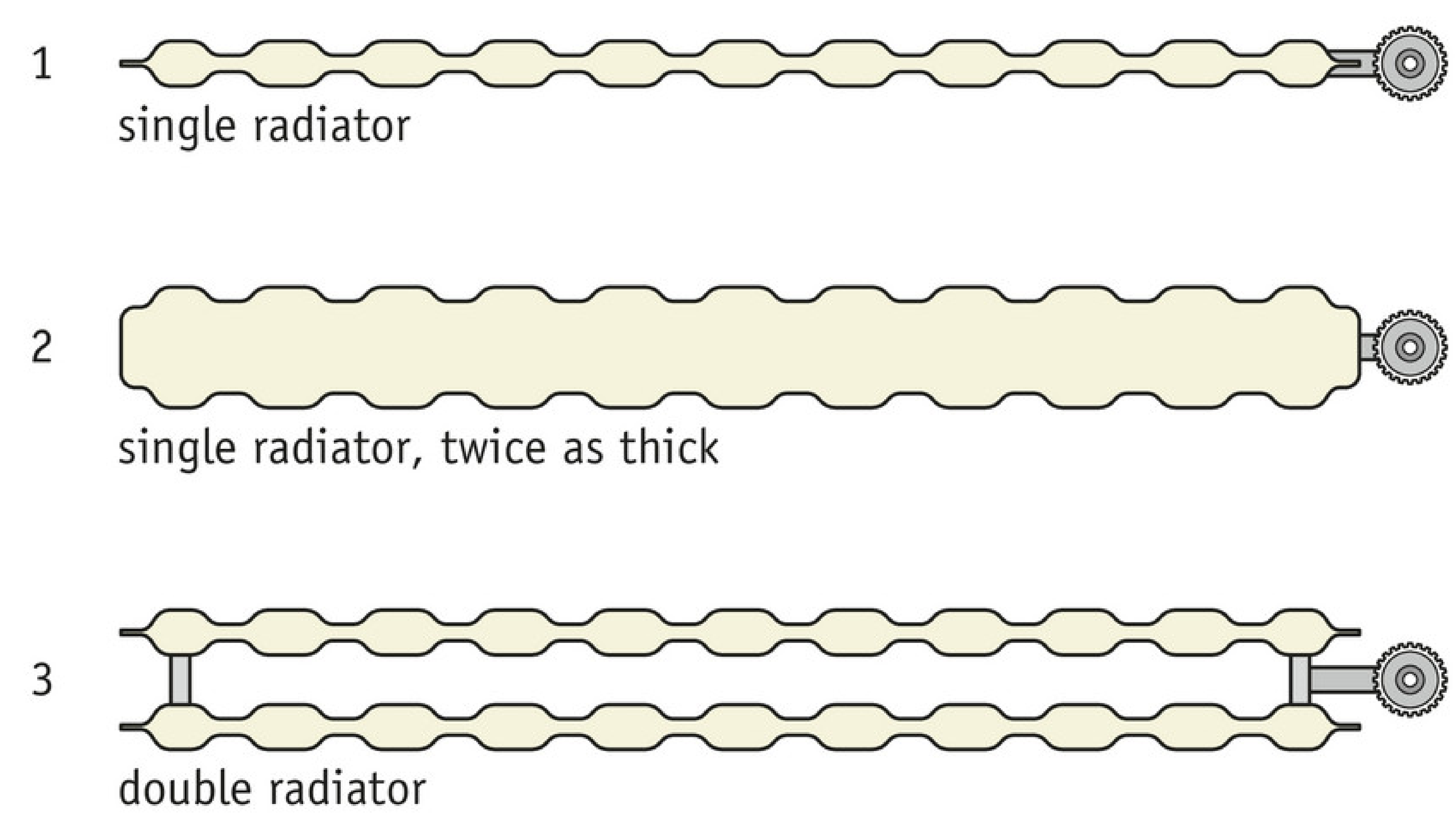
Exercises

23 Answer the questions below.
- **a** In which direction does the heat spread during conduction, convection and radiation?
- **b** Why are you not able to reuse the heat that escapes from a house?
- **c** Why does a central heating boiler keep starting up again after a while in cold weather?
- **d** Why do insulating materials such as polystyrene foam consist largely of air?

24 The temperature in a room that is being warmed by a heater will not keep rising continuously.
Why does it reach a point where the temperature is not rising any more?

25 A certain amount of heat disappears through a wall to the outside every second.
What four factors does the quantity of escaping heat depend on?

26 Three types of radiators are shown in figure 25. The radiators are equally long and equally tall. They are all filled with warm water at the same temperature. The temperature in the surroundings of each of the radiators is also the same.
Explain which radiator will give off the most heat per minute.



▶ **figure 25**
Which radiator will heat a room up fastest?

27 Outdoor skaters who like natural ice hate it when it snows. If there is a thick layer of snow on the ice, the layer of ice will hardly grow any thicker, even if there is a severe frost.
Explain why the ice does not get thicker, even if the air is way below freezing.

28 If it is freezing outside and you take your bike out of the shed, the handlebars will feel much colder than the seat.
Give an explanation for this.

CAVITY WALL INSULATION: A GREAT IDEA!

An ‘empty’ cavity wall insulates less well than many people think. On average, 580 MJ of heat escapes every year through one square metre of cavity wall. That is equivalent to about 18 m^3 natural gas. A well-insulated cavity wall allows far less heat through. The heat loss through that type of wall is only 260 MJ (8 m^3 natural gas) per square metre per year. Having the cavity walls insulated is therefore very much to be recommended. It can save you hundreds of euros a year.

▲ **figure 26**
part of a brochure about cavity wall insulation

29 Sebastian has bought an old house that has no cavity wall insulation. He reads in a brochure that walls like that do not insulate very well (figure 26).

a According to the brochure, how much heat is lost annually:
- through 1 m^2 of a cavity wall that is not insulated?
- through 1 m^2 of a cavity wall that is properly insulated?

b Sebastian gets the cavity walls in his house (a total of 55 m^2) thoroughly insulated.
How much less heat now escapes annually to the outside?

c How many m^3 of natural gas does this let Sebastian save every year?

d How many euros a year will Sebastian's energy bill go down by? 1 m^3 of natural gas costs € 0.65 (including VAT and energy tax, at 2013 price levels).

e The brochure says that cavity wall insulation can ‘save you hundreds of euros a year’.
Do you agree with that statement? Explain your answer.

U-value

The U-value is a measure of the heat loss of a structural element such as a roof, window or floor. There is a good rule of thumb that lets you estimate the natural gas consumption using U-values. The rule is:
The amount of heat energy that disappears outside per cold season through one square metre (of roof, wall or window) is equivalent to 10 x U cubic metres of natural gas.

Some examples:
- single-glazed window: U = 6
- double-glazed window: U = 3
- cavity wall with no filling: U = 1.8
- filled cavity wall: U = 0.8

▲ **figure 27**
a website about the U-values of windows and walls

***30** Suzanne has bought an old house with single-glazed windows. She reads on a website that a lot of heat can be lost through single glazing (figure 27).

a The windows of Suzanne's house have a total area of 14 m^2.
Calculate how many m^3 of natural gas are lost ‘through the windows’ in the cold season.

b Suzanne decides to replace the single glazing with double glazing throughout.
Calculate how many m^3 of natural gas Suzanne saves in the cold season.

c Double glazing costs € 100 per m^2. Natural gas costs € 0.65 per m^3 (2013 price levels).
Work out how long it will take before Suzanne has earned back the cost of the double glazing (assuming that the price of gas does not change).

31 Special protective suits have been developed for firemen that let them walk straight through the flames if necessary.

- **a** The outside of the suit is made of a lightweight, shiny material. Explain why this material is chosen.
- **b** The layer underneath consists of a downy material that contains a lot of air.
  Explain why this material is chosen.

Plus Energy-neutral living

32 An energy-neutral house often has large windows on one side. Heat can get in through those windows, even in the middle of the winter.

- **a** What energy source is helping to heat the house then?
- **b** What form of heat transport gets that heat inside the house?
- **c** Which side of the house is it best to put a window on for this, the north, south, east or west?
- **d** Which side of the house is it better to have only small windows on?
- **e** Why are all the windows of an energy-neutral house made of well-insulating double glazing?

33 The upper storey of the house in figure 24 sticks out quite a long way at one end.
Explain:

- **a** why only the south side of the house has a part that sticks out like that.
- **b** why not very much sunlight gets into the house during the summer.
- **c** why the people living there do get 'a lot of sun inside' during the winter.
- **d** what benefits this kind of construction has for the energy bills.

34 Search the Internet for information about houses that are energy-neutral (or almost).

- **a** What measures are taken to reduce the energy consumption in the house?
- **b** What measures give a (net) positive balance of energy that can be used in the house?
- **c** Is energy used 'from outside'? What does the house provide in return?
- **d** Are there disadvantages to living in an energy-neutral house? If so, what are they?

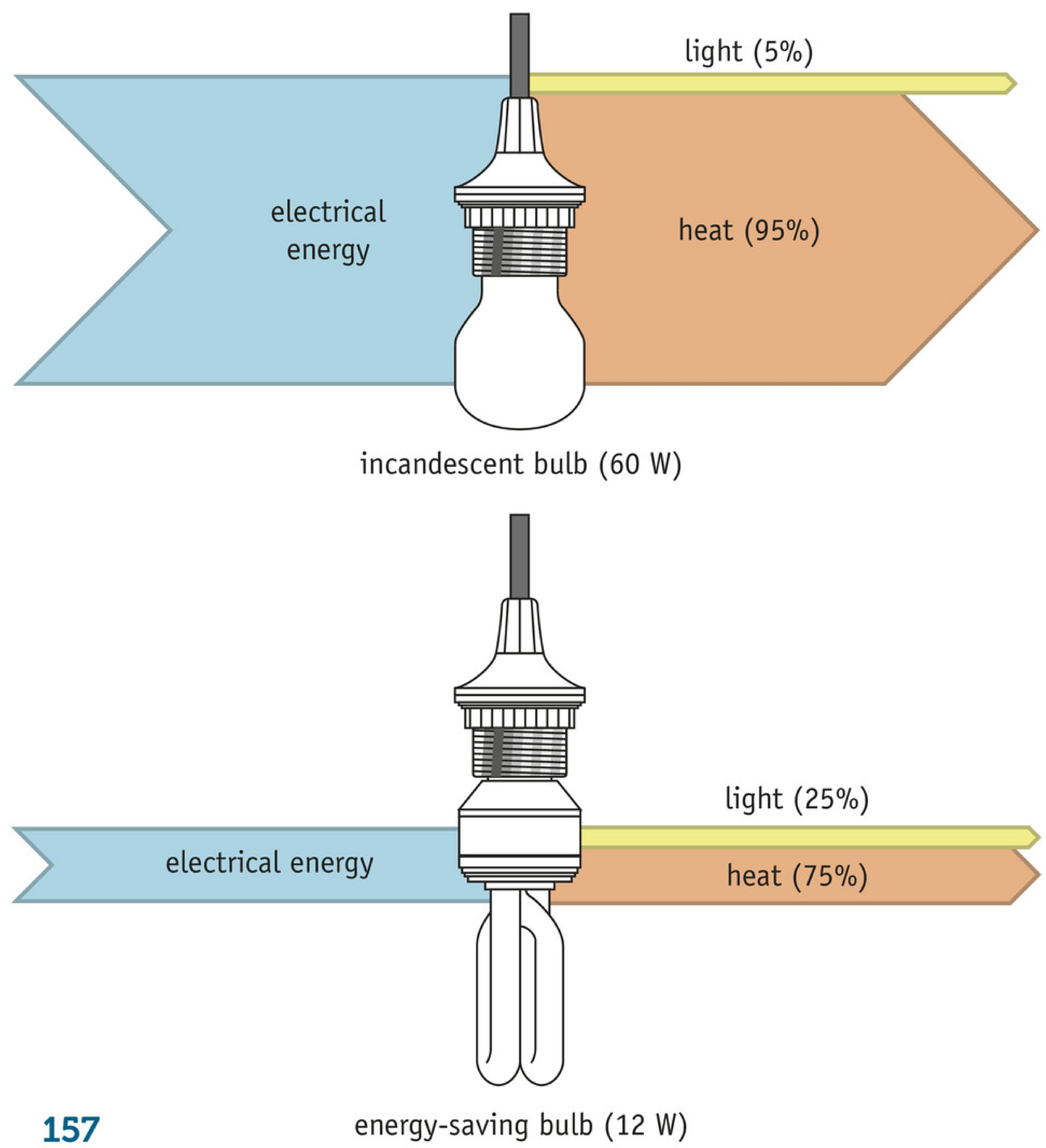
4 Efficiency

There are various benefits to being economical with electrical or chemical energy. You can save money by doing it, you can help make sure that the reserves of natural gas and coal are used up less quickly, and you can help solve environmental problems.

Saving energy

You can see from the formula $E = P \cdot t$ that there are two ways of saving energy. You can make the power P smaller by buying energy-efficient appliances such as a high energy boiler (HE boiler) or an energy-efficient tumble dryer. Or you can make t smaller by using the appliances you already have less often or for less long. For instance, if you set the thermostat a little lower, the central heating will not come on so often and will therefore use less natural gas.

That one appliance has a lower power rating than another does not necessarily mean a great deal. There is only any point to the comparison if the two devices are doing something similar. You can compare the power consumption of two bulbs that give the same amount of light, for example, an incandescent bulb and an energy-saving bulb. You will see that an energy-saving bulb has a much lower power rating than a comparable incandescent bulb. Because the difference is so big, you are no longer even allowed to sell incandescent bulbs!



▶ **figure 28**
two energy flow diagrams

Figure 28 shows you flow diagrams which indicate the proportion of output energy emitted as light and heat for an incandescent bulb and an energy-saving bulb. An incandescent bulb only converts 5% of the electrical energy into light; the rest is converted into heat. You can then say that the **efficiency** of the incandescent bulb is 5%. An energy-saving bulb does rather better, it converts 25% of the electrical energy into light. The efficiency of that type of bulb is therefore 25%.

Calculating the efficiency Experiment 5

You can calculate the efficiency of a device using the formula:

$$\eta = \frac{E_{useful}}{E_{tot}} \cdot 100\%$$

where E_{useful} is the amount of energy that is usefully consumed. For a bulb, that is the amount of energy that is converted into light. E_{tot} is the total amount of energy that is consumed. In a bulb, that is the electrical power it uses.

You also get the right answer, of course, if you fill in:
- the amount of energy per second that is used usefully;
- the amount of energy that is consumed per second overall.

In other words, you can also calculate the efficiency by dividing the useful power by the total power.

$$\eta = \frac{P_{useful}}{P_{tot}} \cdot 100\%$$

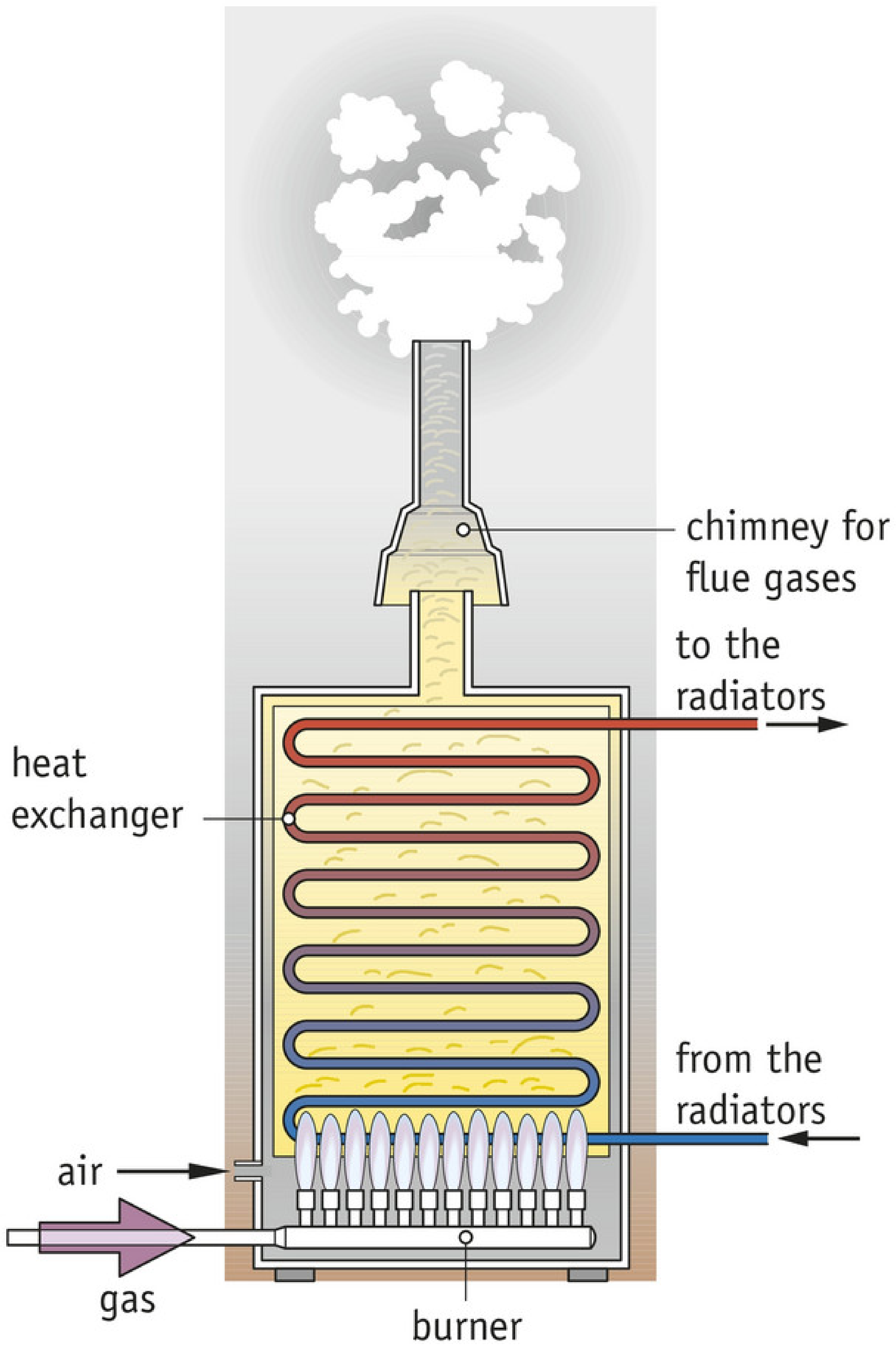
▲ **figure 29**
The roof of this alpine hut has space for three solar panels of 1.8 m^2.

Worked example 4
When the Sun is shining brightly, the incoming radiant energy is 1000 W/m^2. A solar panel with a surface area of 1.8 m^2 then generates 210 W of power (figure 29).
Calculate the efficiency of this solar panel.

data $P_{tot} = 1.8 \times 1000 = 1800$ W
$P_{useful} = 210$ W

required $\eta = ?$

working $\eta = \frac{P_{useful}}{P_{tot}} \cdot 100\% = \frac{210}{1800} \times 100\% \approx 12\%$



▲ **figure 30**
cross-section of a central heating boiler

The efficiency of a central heating boiler

Natural gas gets burned in the boiler of a central heating system (figure 30). The hot combustion gases that this produces go past pipes that water is flowing through, the heat exchanger. Part of their heat is then transferred to the water. The remaining heat disappears outside along with the combustion gases.

To determine E_{tot} (the total amount of energy used) by a central heating boiler, you need to know how much heat the gas that was burned had produced. There are two pieces of data you need for that calculation, the volume of natural gas burned (in m^3) and the **calorific value** of the fuel. The calorific value of Dutch natural gas is 32 MJ/m^3. That means that 32 MJ (32 million joules) of heat are released if you burn 1 m^3 of natural gas.

To determine E_{useful} (the amount of usefully used energy), you have to determine how much of that heat ended up in the water. To find that out, you measure the mass m and the temperature increase ΔT for the water that has been heated up. You can then calculate the amount of heat that the water has taken up using the formula $Q = c \cdot m \cdot \Delta T$.

If you know E_{tot} and E_{useful}, you can finally calculate the efficiency of the central heating boiler. Tests have shown that central heating boilers fifty years ago were about 65% efficient. The efficiency of a modern HE boiler is above 90%.

Worked example 5

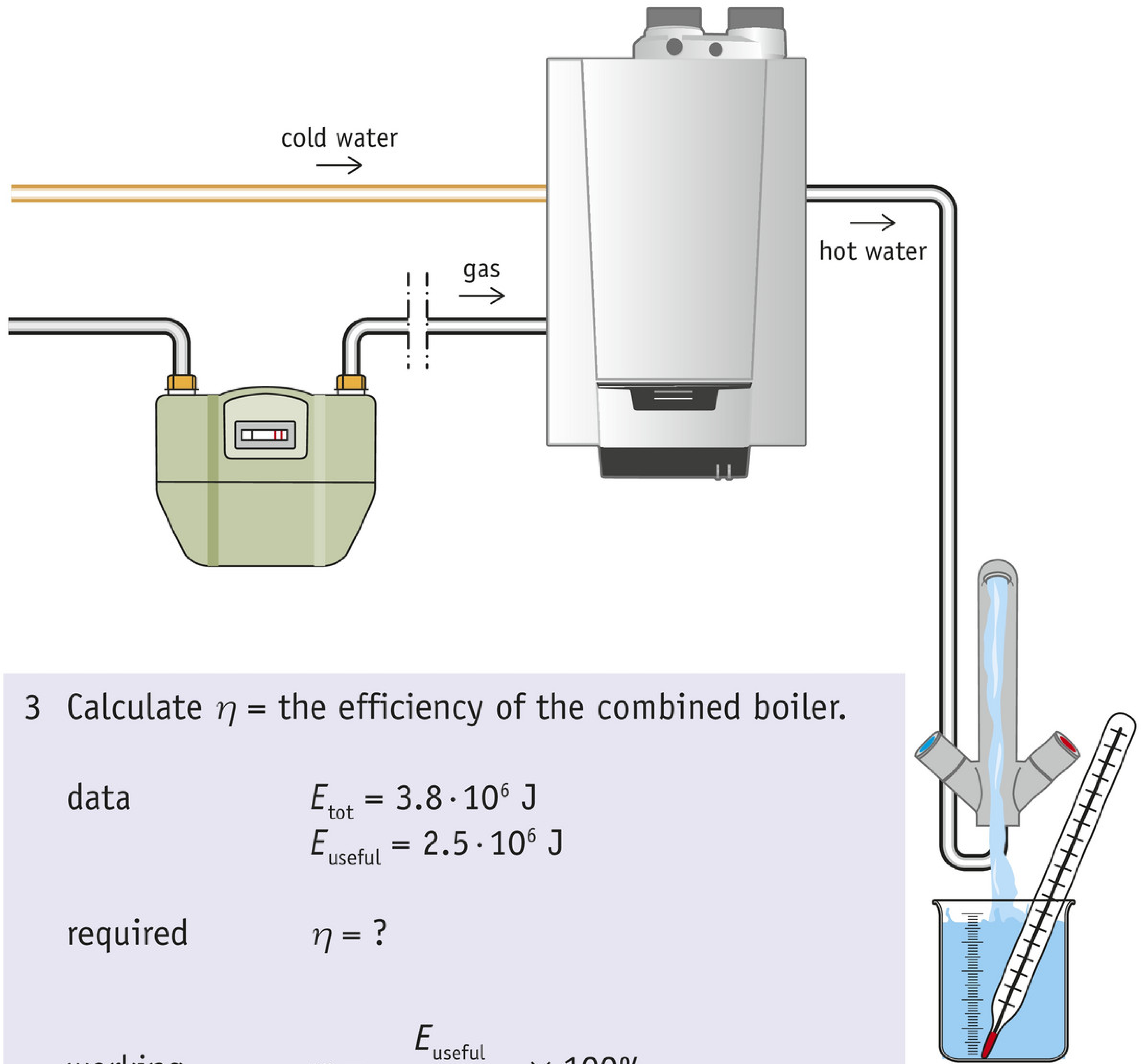
A combined heating and hot water boiler burns 0.12 m^3 of natural gas in 4.0 minutes. During those 4.0 minutes, 11 litres of water are heated from 18 °C to 72 °C (figure 31).
Calculate the efficiency of the combined boiler.

1 Calculate E_{tot} = the amount of heat the natural gas has provided.

data	0.12 m^3 natural gas has been burned. The calorific value of natural gas is 32 MJ/m^3.
required	$E_{tot} = ?$
working	$E_{tot} = 0.12 \times 32 \approx 3.8$ MJ

2 Calculate E_{useful} = the amount of heat that ended up in the water.

data	The mass m of 11 L water = $1.1 \cdot 10^4$ g. The temperature increase $\Delta T = 72 - 18 = 54$ °C. The specific heat c of water = 4.2 J/g·°C.
required	$E_{useful} = ?$
working	$Q = c \cdot m \cdot \Delta T = 4.2 \times 1.1 \cdot 10^4 \times 54 \approx 2.5 \cdot 10^6$ J



▶ **figure 31**
This is how you can determine the efficiency of a combined heating/hot water boiler.

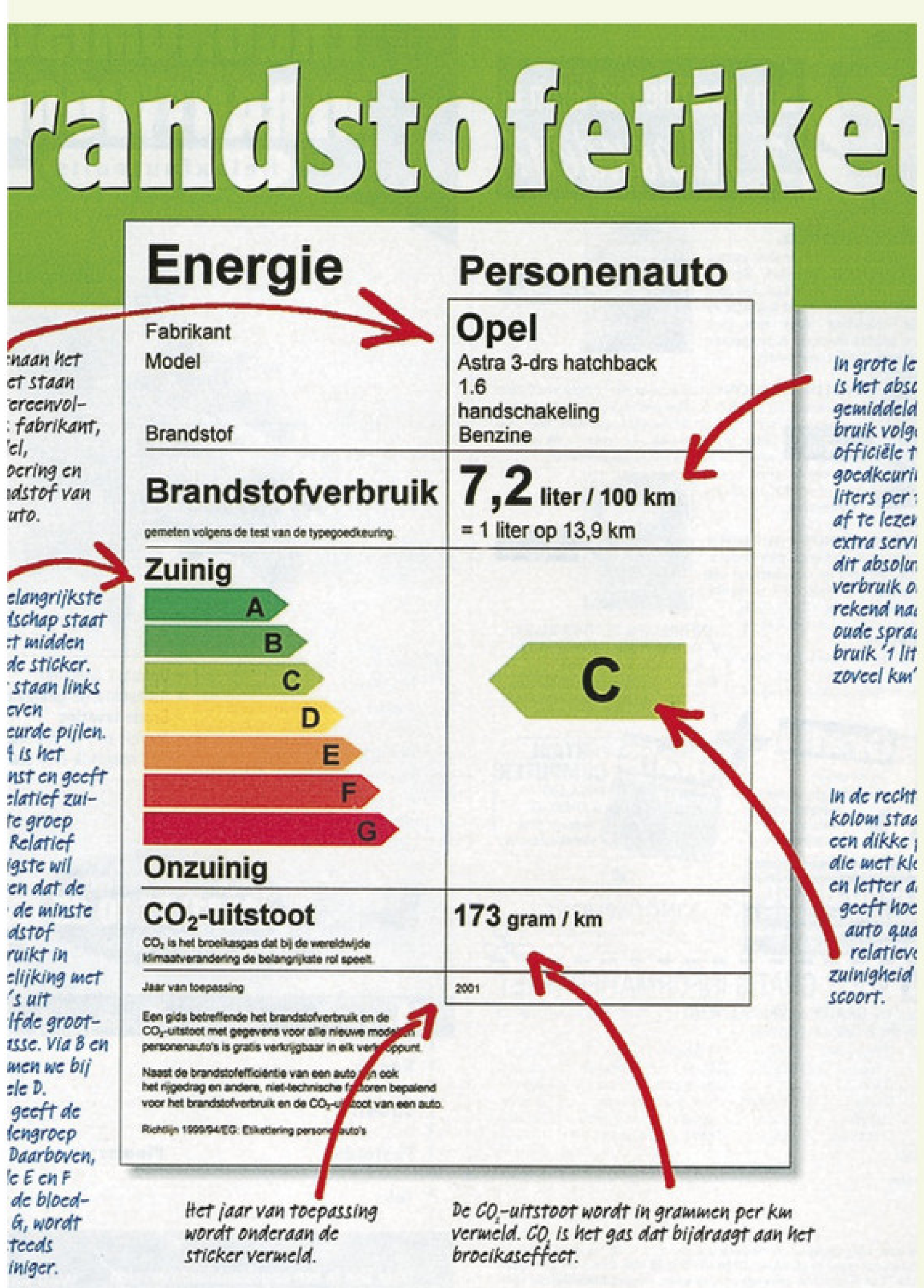
3 Calculate η = the efficiency of the combined boiler.

data $E_{tot} = 3.8 \cdot 10^6$ J
$E_{useful} = 2.5 \cdot 10^6$ J

required $\eta = ?$

working $\eta = \dfrac{E_{useful}}{E_{tot}} \times 100\%$

$$= \frac{2.5 \cdot 10^6}{3.8 \cdot 10^6} \times 100\% \approx 66\%$$



Plus The fuel efficiency label

The government would like people to be more economical about their energy consumption. What kind of car you drive can make quite a difference. But how can you find out whether a car is economical or not? To help people with this, every new car has a **fuel efficiency label** (figure 32).

The fuel efficiency label shows you how economical the car is compared to other, similar models. An economical car gets a green arrow, a gas guzzler gets a red one. This lets you compare different cars better. The label also tells you how many grams of CO_2 the car produces per kilometre it is driven.

◀ **figure 32**
A fuel efficiency label will look something like this.

Exercises

35 Answer the questions below.
- **a** What does the formula $E = P \cdot t$ tell you about how to make savings on your energy bill?
- **b** Why are shops no longer allowed to sell incandescent bulbs?
- **c** What formulae can you use to calculate the efficiency of an appliance?
- **d** What does the calorific value of a fuel mean?

36 You need to make various measurements in order to determine the efficiency of a combined heating/water boiler.
What measuring instrument can you use for measuring:
- **a** how many cubic metres of gas have been burned?
- **b** how much hot water the combined boiler has produced?
- **c** how much that water increased in temperature by?

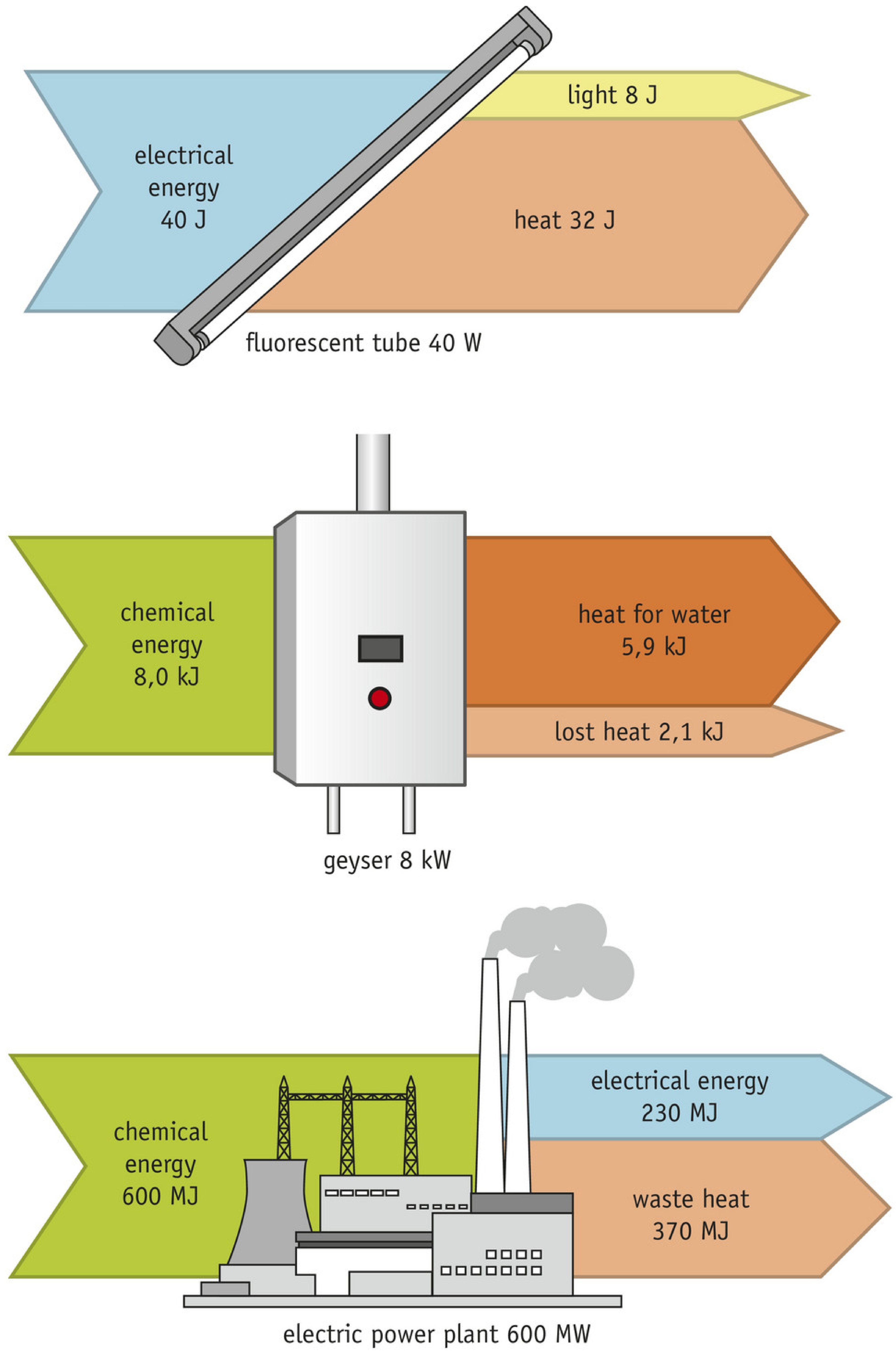
37 Burning 1 m^3 of natural gas generates 32 MJ of heat.
Calculate how many MJ of that is actually used usefully:
- **a** in an old-fashioned central heating boiler (η = 75%).
- **b** in a modern HE boiler (η = 90%).

38 You see solar cells on house roofs more and more often now.
- **a** What energy source does a solar cell use?
- **b** What type of energy does this energy source provide?
- **c** What type of useful energy does a solar cell then give?
- **d** Why is it important for the efficiency of solar cells to be improved?

39 A combined heating and hot water boiler burns 0.30 m^3 of natural gas in 10 minutes. During those 10 minutes, 28 litres of water are heated from 15 °C to 85 °C.
Calculate:
- **a** the amount of heat released by the combustion of the natural gas.
- **b** the amount of heat taken up by the water that has been heated.
- **c** the efficiency of the combined heating/water boiler.

40 An electric bottle warmer has a power rating of 80 W. It takes 8.5 minutes for the temperature of the 200 g of water in the baby's bottle to rise from 7 °C to 37 °C.
- **a** Calculate the efficiency of the bottle warmer. Show all your calculation steps.
- **b** A bottle warmer is not very efficient. State two reasons why (think them up for yourself).

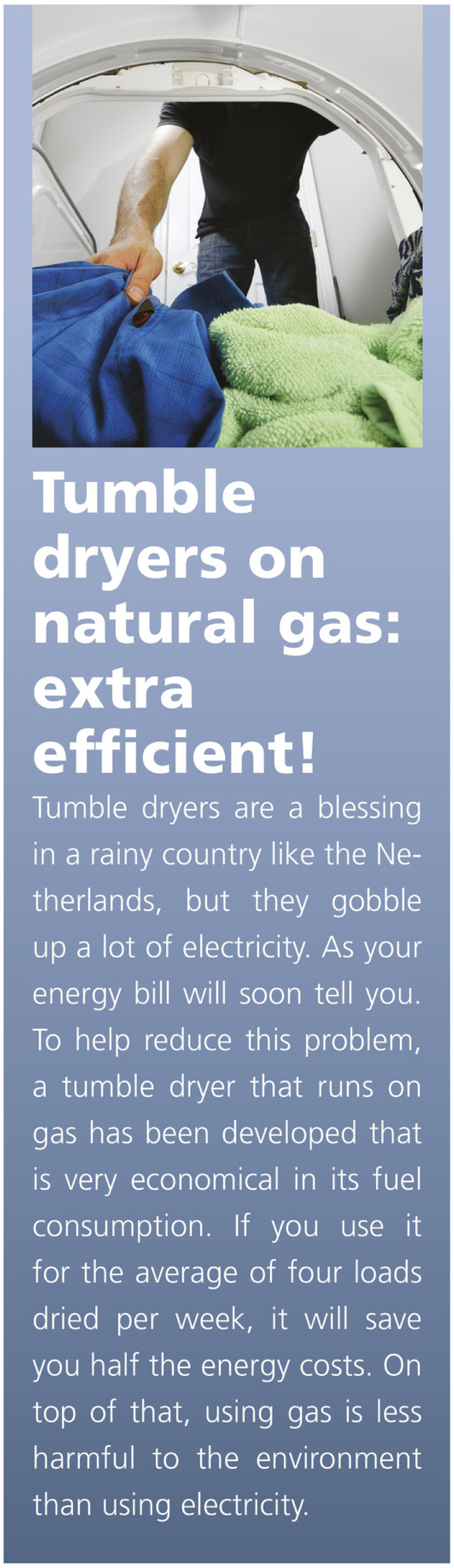
41 Figure 33 shows you three energy flow charts.
Calculate the efficiency of each of the energy conversions.



▶ **figure 33**
three energy flow diagrams

***42** You need worksheet 4-3 for this exercise.
Mahmood's desk light has a halogen bulb. The bulb is connected to the socket via a mains adapter. The adapter consumes 24 W of electric power (at a voltage of 230 V) and gives out 19 W of electric power (at a voltage of 12 V).

a Calculate the efficiency of the adapter.
b What happens to the 5 W of power that is not usefully used?
c What might Mahmood notice if he touches the adapter?
d Complete the energy flow chart on the worksheet. Make sure each arrow is the right width.
e The efficiency of the bulb is 25%.
Draw the energy flow chart for the light and adapter together.
f Calculate the efficiency of the adapter and the light together.



43 In figure 34 you can see part of a brochure about gas-powered tumble dryers.
- **a** List two arguments in favour of choosing a gas-powered tumble dryer.
- **b** Why is using gas less of a burden on the environment than using electricity (even if the electrical power plant burns natural gas)?
- **c** What method of drying your washing is even more environmentally friendly than one of these gas-powered dryers?

***44** The amount of solar radiation that falls on a solar panel containing solar cells also depends on the angle of incidence (the angle at which the radiation hits the panel). If sunlight falls perpendicularly onto a solar panel, its maximum power in the Netherlands is 1000 W/m^2.
- **a** In practice, the power of the solar radiation is generally much less. List two reasons for this.
- **b** Draw the energy flow chart for a solar panel with an efficiency of 15%.
- **c** A solar panel has a surface area of 8.0 m^2 and an efficiency of 15%. Calculate the maximum electrical power that this solar panel can produce.
- **d** As a rule of thumb, you can say that a solar panel will produce 95 kWh per m^2 each year.
  Calculate how many hours of maximum solar radiation that would need.

Plus The fuel efficiency label

45 Study the fuel efficiency label in figure 32.
- **a** What two ways of indicating the car's fuel consumption are used?
- **b** Use a calculation to show that the two methods agree.
- **c** During a journey, the car emits 16.2 kg of CO_2.
  How many kilometres did the car drive?

46 A car with an A energy label can easily end up using more petrol than a car with a C label, even if both cars drive exactly the same distance. Give three possible causes for this.

◀ **figure 34**
advertisement for tumble dryers

Experiments

Experiment 1 The specific heat of water 30 min

Introduction
The amount of heat required to increase the temperature of 1 g of any substance by 1 °C is called the specific heat of that substance.

Aim
You are going to determine the specific heat of water.

Requirements
- calorimeter or insulated glass beaker (500 mL) with a lid
- thermometer
- immersion coil
- measuring cylinder
- stopwatch

Doing the experiment and writing it up
Measuring
- Put 500 mL water (measured as precisely as possible) into the glass beaker.
- Place the immersion coil in the water, but do not turn it on yet. Put the lid on the glass beaker (figure 35).
- Measure the initial temperature of the water.
- Connect up the immersion coil. Measure how long it takes to make the temperature of 500 mL of water rise by 20 °C.

1 Make a note of the power rating of the immersion coil, the starting temperature and the time required in your exercise book.

- After doing the experiment, take the plug out of the socket straight away.

Writing up

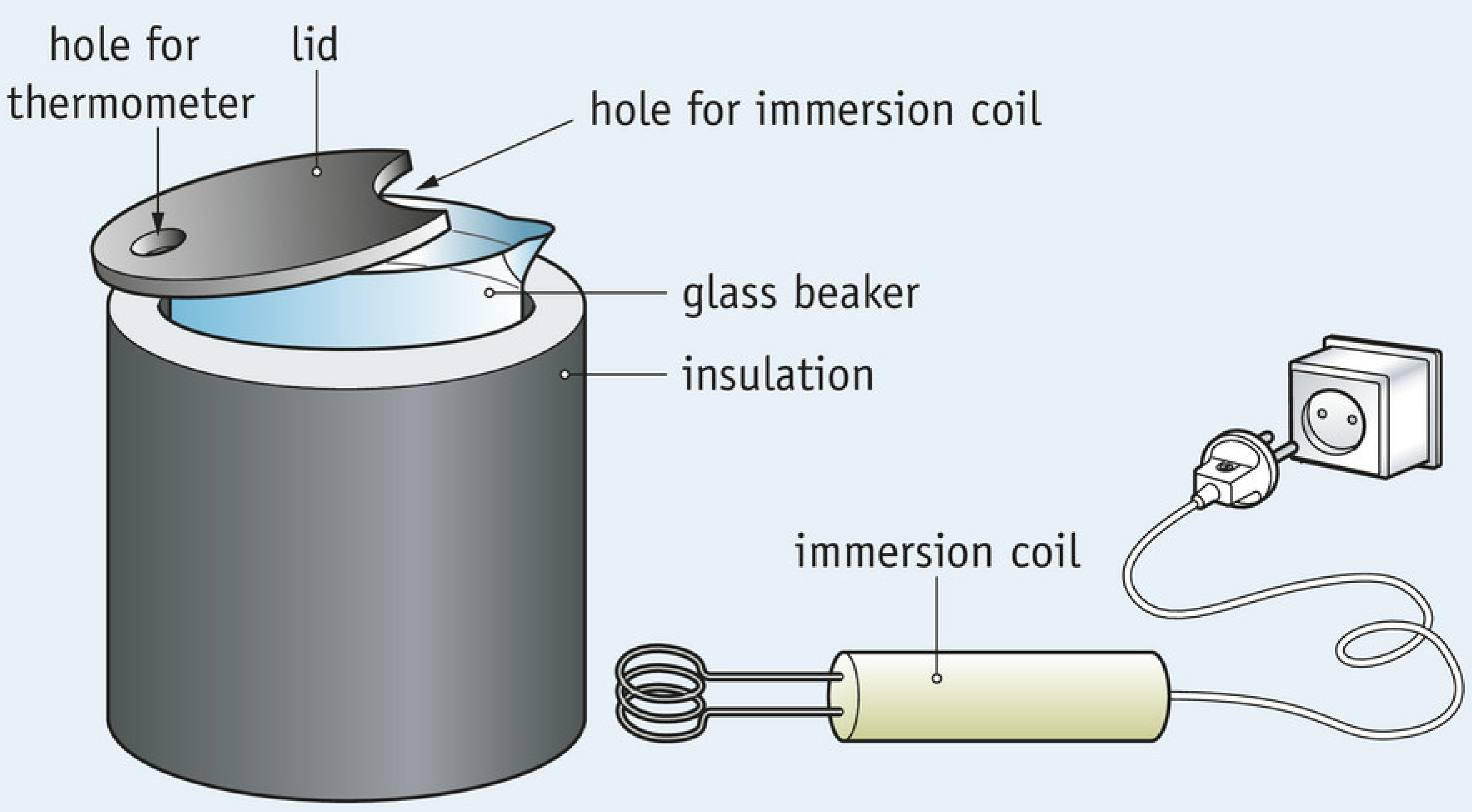
2 Use the formula $E = P \cdot t$ to calculate how much heat the immersion coil has given off.

3 Calculate the specific heat c of water using the formula $Q = c \cdot m \cdot \Delta T$.

4 Compare your result against the value given in paragraph 1.
How big is the difference?

5 Explain why the experiment that you carried out will probably give a value for the specific heat that is too high.

6 How could you determine the specific heat of water more accurately? Describe what you would have to change in the experiment to achieve this.



▲ figure 35
the setup for experiment 1

Experiment 2 The temperature of a gas flame 45 min

Introduction
When you heat something with a Bunsen burner, you often use a blue flame that makes a slight roaring or hissing noise. The temperature of that flame remains constant as long as you do not adjust the gas control knob or the air control ring.

Aim
In this experiment, you are going to investigate how hot the gas flame is. The question you are studying is:
What is the temperature of a blue gas flame that is hissing a little?

Requirements
- insulated glass beaker with a lid
- a large stainless steel screw
- long tongs
- Bunsen burner
- thermometer
- measuring cylinder
- scales

Doing the experiment and writing it up
If you hold a steel screw in a gas flame for a few minutes the temperature of the screw will be the same as that of the gas flame. If you then quickly immerse the hot screw in a glass beaker full of water, the temperature of the water will rise (as the water absorbs the heat). At the same time, the temperature of the screw will fall (it gives off heat). After a little while, the water and the screw will end up at the same final temperature. In the ideal case, the water will absorb exactly as much heat as the screw loses. You are going to use that fact to determine the temperature of the screw.

Measuring
- Put 100 mL water in the glass beaker.
- Measure the initial temperature of the water.
- Determine the mass of the screw.
- Light the burner and set it to a quietly hissing blue flame.
- Use the long tongs to hold the screw in the gas flame for a few minutes.
- Then immerse the screw as quickly as possible in the water. Put the lid on the beaker.
- Determine the final temperature T_e. This is the highest temperature that the water reaches before it starts cooling down again.

1 Write down all the measurement data neatly in your exercise book.

Writing up

2 Calculate how much heat the water in the beaker has absorbed. You can find a value for the specific heat of water in section 1.

3 Calculate how much heat the screw has transferred to the water. The specific heat of stainless steel c_{ss} is 0.46 J/g·°C. Put c, m and T_e into the formula, but leave the initial temperature of the screw T_i alone for the moment.

4 Assume that the heat absorbed equals the heat transferred. This lets you calculate the initial temperature T_i of the screw. This is a good approximation to the temperature of the gas flame.

5 Is the temperature you have calculated for question 4 going to be too high or too low? Explain.

6 See 'Skills 10' at the back of the book. Make a report of the experiment that you have carried out.

Experiment 3 Conduction of heat 15 min

Introduction
Some substances are good conductors of heat. Other substances only let heat pass through them very slowly. Which group does copper belong to, do you think, and what about plastic?

Aim
In this experiment, you will be investigating how well copper and plastic conduct heat.

Requirements
- glass beaker
- lid
- hot water
- strip of plastic
- strip of copper

Doing the experiment and writing it up

- Fill the glass beaker three-quarters full with hot water.
- Put the lid on the glass beaker. Put the copper strip into the hot water, underneath the lid.
- Take hold of the copper strip just above the edge of the glass beaker (figure 36).

1 What do you notice?

- Take hold of the copper strip 3 cm further up when it gets too hot for your fingers.

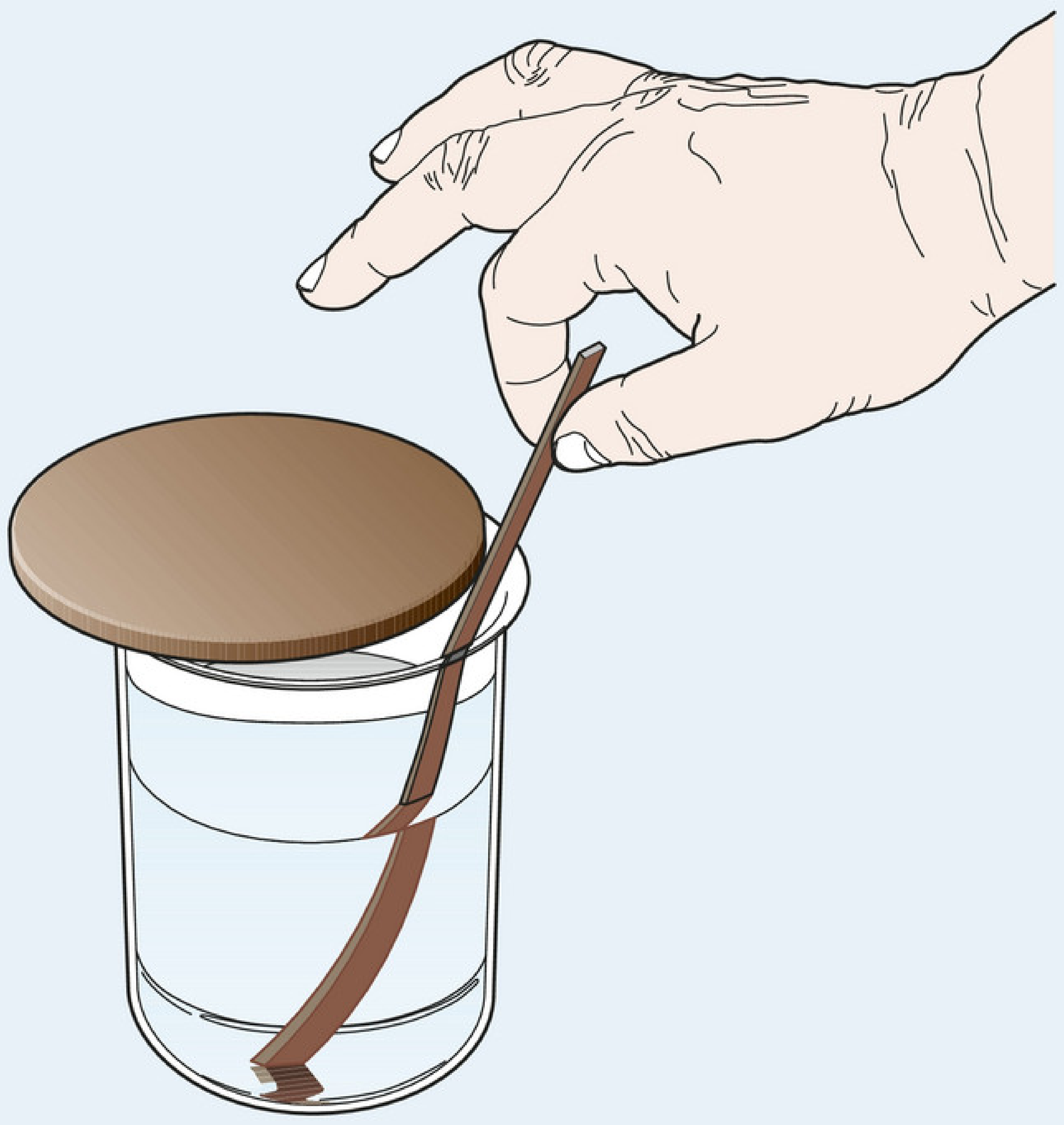
2 How long does it take before the strip gets too hot to hold here as well?

- Take hold of the strip another 3 cm higher. Finally, take hold of the strip at the far end.

3 Where is the strip hottest? Where is the strip least hot?
4 In what direction has the heat spread through the strip?

- Repeat this experiment using a plastic strip instead of a copper strip.

5 What conclusions can you draw from your observations?



▲ figure 36
How to hold the copper strip.

Experiment 4 Flows in water 15 min

Introduction

If water is heated at one place, a convective flow will occur. This allows the heat to spread.

Aim

In this experiment, you will investigate how water flows when you heat it.

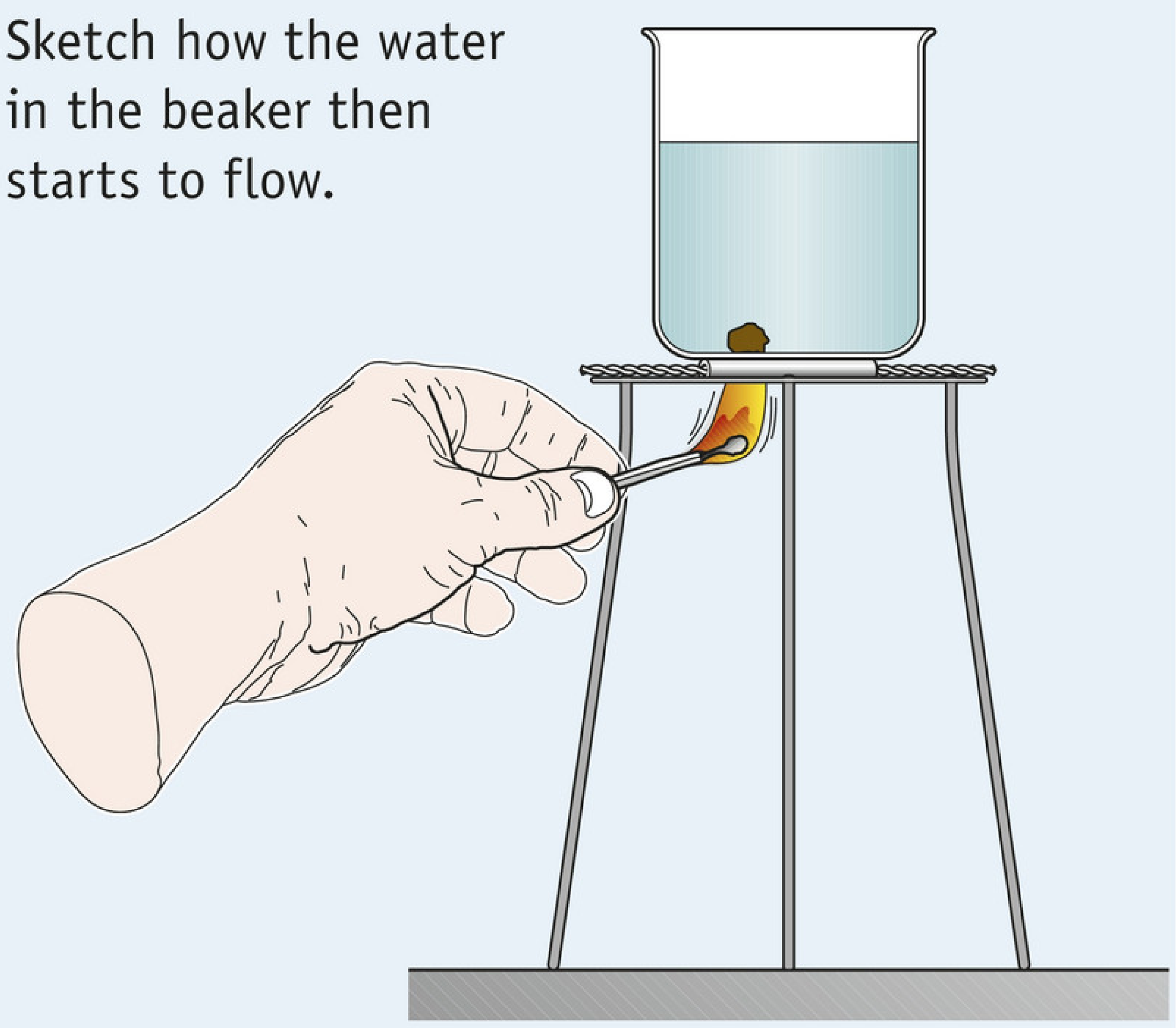
Requirements

- tripod
- pipe-stem triangle
- glass beaker
- a crystal of potassium permanganate
- matches

Doing the experiment and writing it up

- Fill the glass beaker two-thirds full with water. Set the experiment up as shown in figure 37.
- Carefully drop a crystal of potassium permanganate down one side into the glass beaker.
- Use a match to heat the glass beaker directly underneath where the potassium permanganate crystal is.

1 Sketch how the water in the beaker then starts to flow.



▲ figure 37
How to heat the water in the beaker.

Experiment 5 The efficiency of a tea light 30 min

Introduction
You can use a small candle such as a tea light to heat water. Part of the heat from the candle then ends up transferred into the water. Another fraction of the heat is lost. The efficiency of this form of heating is therefore clearly not 100%. But how much is it, actually?

Aim
You are going to investigate that in this experiment. The question you are studying is:
What is the efficiency when you heat water using a tea light?

Requirements
- tripod
- wire mesh
- 100 mL glass beaker
- measuring cylinder
- thermometer
- scales
- tea light
- matches

Doing the experiment and writing it up
Preparation
A burning candle loses weight as it burns. This is because the combustion products (water vapour and carbon dioxide) are gaseous and end up spread out through the classroom. By weighing the candle before and after the experiment you can determine how many grams of fuel have been burned.

Measuring
- Determine the initial mass of the tea light (candle).
- Put 50 mL water in the glass beaker.
- Measure the initial temperature of the water.

1 Make a note of the initial mass and the initial temperature.

- Set the experiment up as shown in figure 38. Light the candle.
- Stir occasionally with the thermometer.
- Measure the temperature of the water again after 6 minutes.
- Blow the tea light out carefully.
- Determine the mass of the candle again.

2 Make a note of the final mass and the final temperature.

Writing up
3 Every 1.0 g of the tea light that is burned gives 40 kJ of heat.
Calculate how much heat was given off by the tea light.
4 Look in the theoretical section to find the specific heat of water.
Work out how much heat the water absorbed.
5 Use your answers to questions 3 and 4 to calculate the efficiency.
6 Compare the value you got for the efficiency against the values your classmates got.
Why did everyone get a different value?
7 How could you improve the efficiency of the tea light?

▲ figure 38
the setup for experiment 5

Experiment 6 The voltage of a solar panel 45 min

Introduction
Suppose that a solar panel gives the greatest voltage (and the most electrical energy) when it is precisely facing the Sun. If the direction is not ideal, the voltage will be lower. An energy company wants to tell its customers exactly how the direction affects the output of the solar panels. In this task, you are the researcher who has to gather the data they need.

Aim
How much lower is the voltage? You are going to investigate that in this experiment. The question you are studying is:
What is the relationship between the direction a solar panel is facing and the voltage that it generates?

Requirements
For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up
- Think how you can give the most reliable answer to the question. What is your test setup going to look like; what exactly are you going to measure; how will you make sure that the measurements are repeatable (and can therefore be verified)?

1 Make a work plan for this study.

- The work plans will be discussed with the rest of the class at the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Write down all the measurements, calculations and results in your exercise book.

- Your teacher will tell you whether or not you have to write up a report on this experiment.

Test Yourself

You can also do questions 1 to 16 on the computer.

1 What energy conversion takes place:
- **a** in a central heating boiler?
- **b** in an iron?

2 Copy and complete:
- **a** Energy can be converted from one form into another, but this does not change the overall ... of energy.
- **b** A rise in the temperature of a substance means that the molecules in the substance are moving more ... on average.
- **c** You can measure how much heat is required to heat a certain amount of water using a ....
- **d** The amount of heat required to increase the temperature of 1 g of any substance by 1 °C is called the ... of that substance.

3 Stephanie heats 250 mL water from 15 to 100 °C. How much heat does the water absorb?
- A 57 kJ
- B 73 kJ
- C 89 kJ
- D 105 kJ

4 Four 'alternative' energy sources are listed below. For each energy source, state the type of energy that it provides.
- **a** geothermal
- **b** biomass
- **c** wind
- **d** sunlight

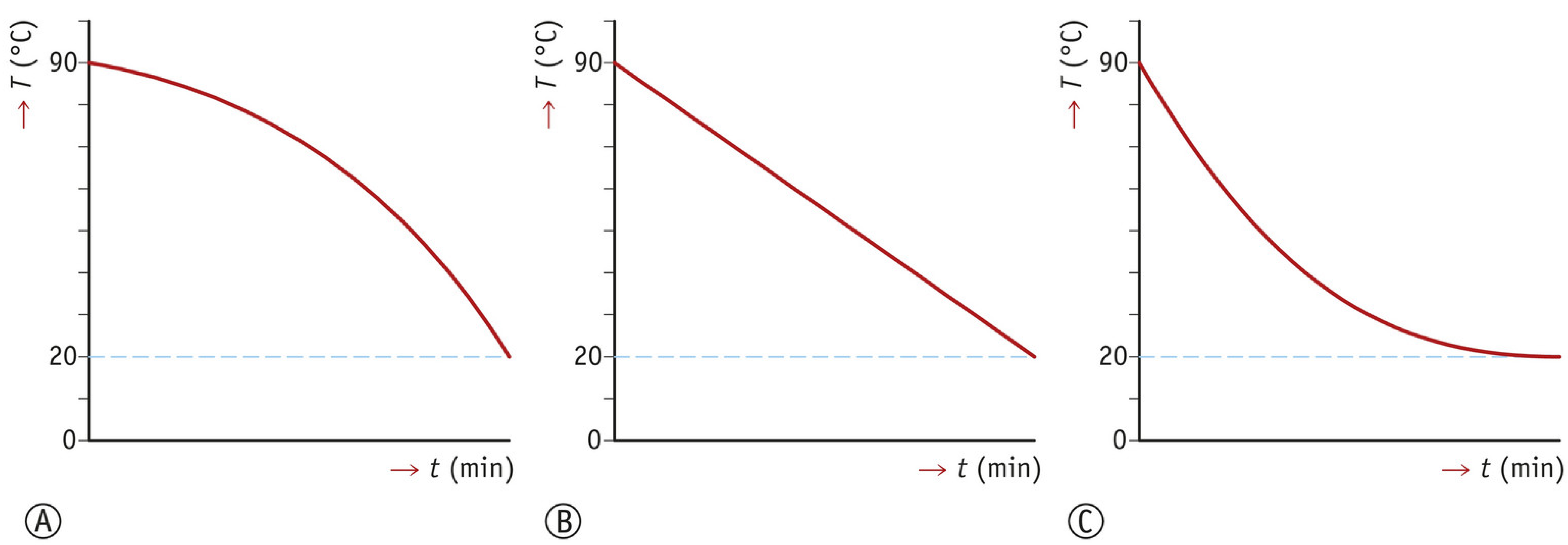
5 Martin has a kettle with a power rating of 2400 W.
- **a** Calculate how much heat this kettle produces per minute in kJ.
- **b** He fills the kettle with 750 mL water at 15 °C. Calculate how long it will take before the water boils if no heat escapes.

6 Ewan states, "You can calculate the useful power from a wind turbine using the formula $P = U \cdot I$." Neil says, "The useful power of a wind turbine is not constant, but depends on the wind speed." Which statement below is correct?
- A Ewan and Neil are both wrong.
- B Ewan is right but Neil is wrong.
- C Ewan is wrong but Neil is right.
- D Ewan and Neil are both right.

7 State whether the following statements are true or false.
- **a** The planet's stocks of fossil fuels are not unlimited – they are finite.
- **b** Biomass is a fossil fuel, just like natural gas, petroleum and coal.
- **c** Wind power is a clear energy source that has no drawbacks whatsoever for the environment.
- **d** A solar collector produces heat that can be used for heating water.
- **e** Coal is used in a number of electricity power plants in the Netherlands.

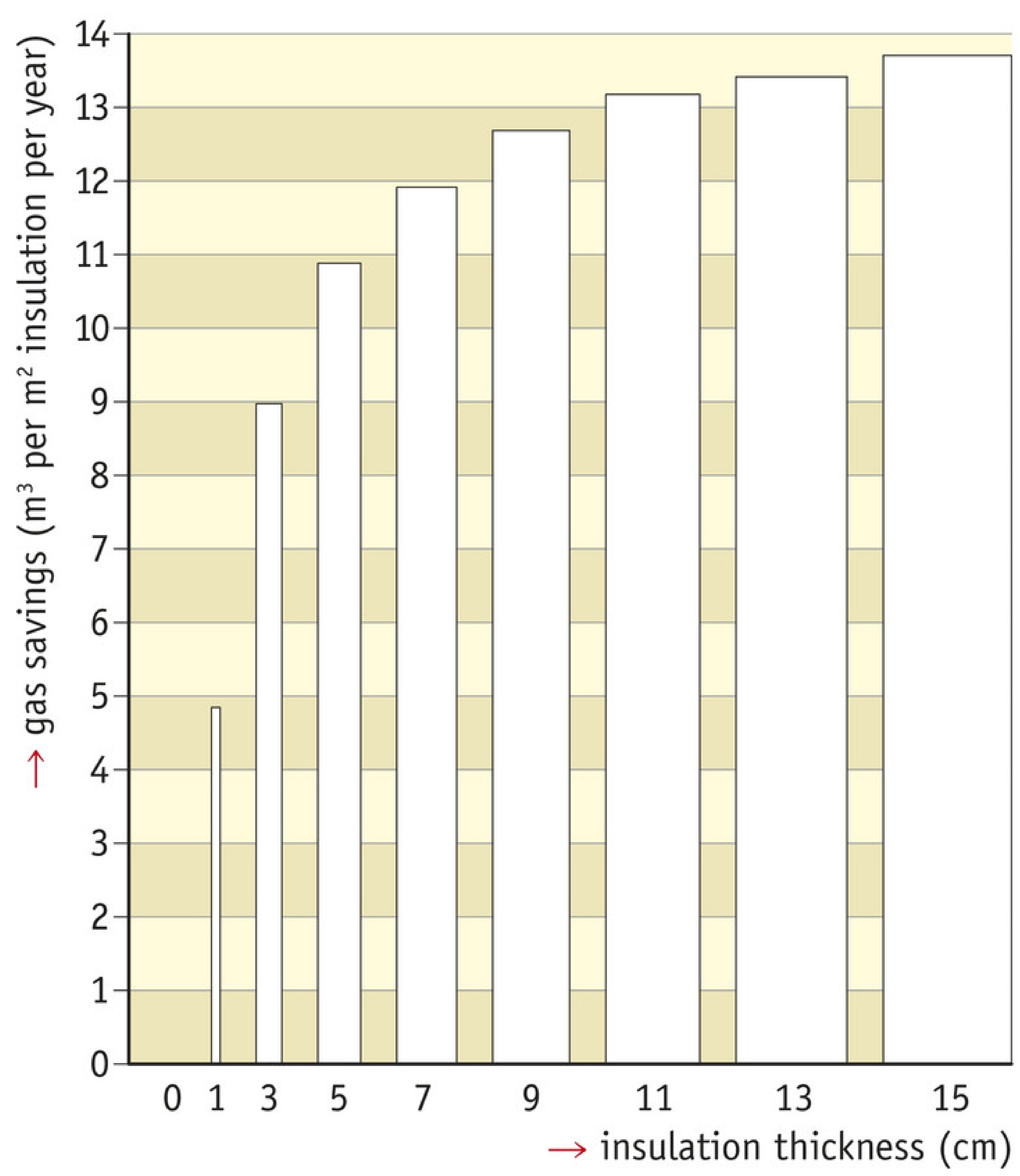
8 A glass of water at a temperature of 90 °C cools down to a room temperature of 20 °C. Which of the graphs in figure 39 is the best representation of how the temperature changes?

▼ **figure 39**
How does the temperature of the water fall?



9 If you want to know if your house is properly insulated, you can have a thermogram made. You do that at a time when it is cold outside and warm inside. The thermogram then lets you read off the temperatures of the walls, the windows, the doors, the roof and so forth.
Select the correct options.
The parts of a house that do not let much heat through are at a *high / low* temperature and emit a relatively *large / small* amount of radiation. Places where a large amount of heat escapes have a particularly *high / low* temperature. Windows have a *higher / lower* temperature than walls. Windows with double glazing have a *higher / lower* temperature than single-glazed windows.

10 Mrs Decker wants to have her house insulated. In a consumer magazine, she comes across the graph that is shown in figure 40. After she has looked at the graph, she decides to use insulation that is 7 cm thick. In total, she gets a wall area of 62 m^2 insulated.
How many m^3 of natural gas will Mrs Decker save annually, according to the graph?



▲ **figure 40**
information about insulation material

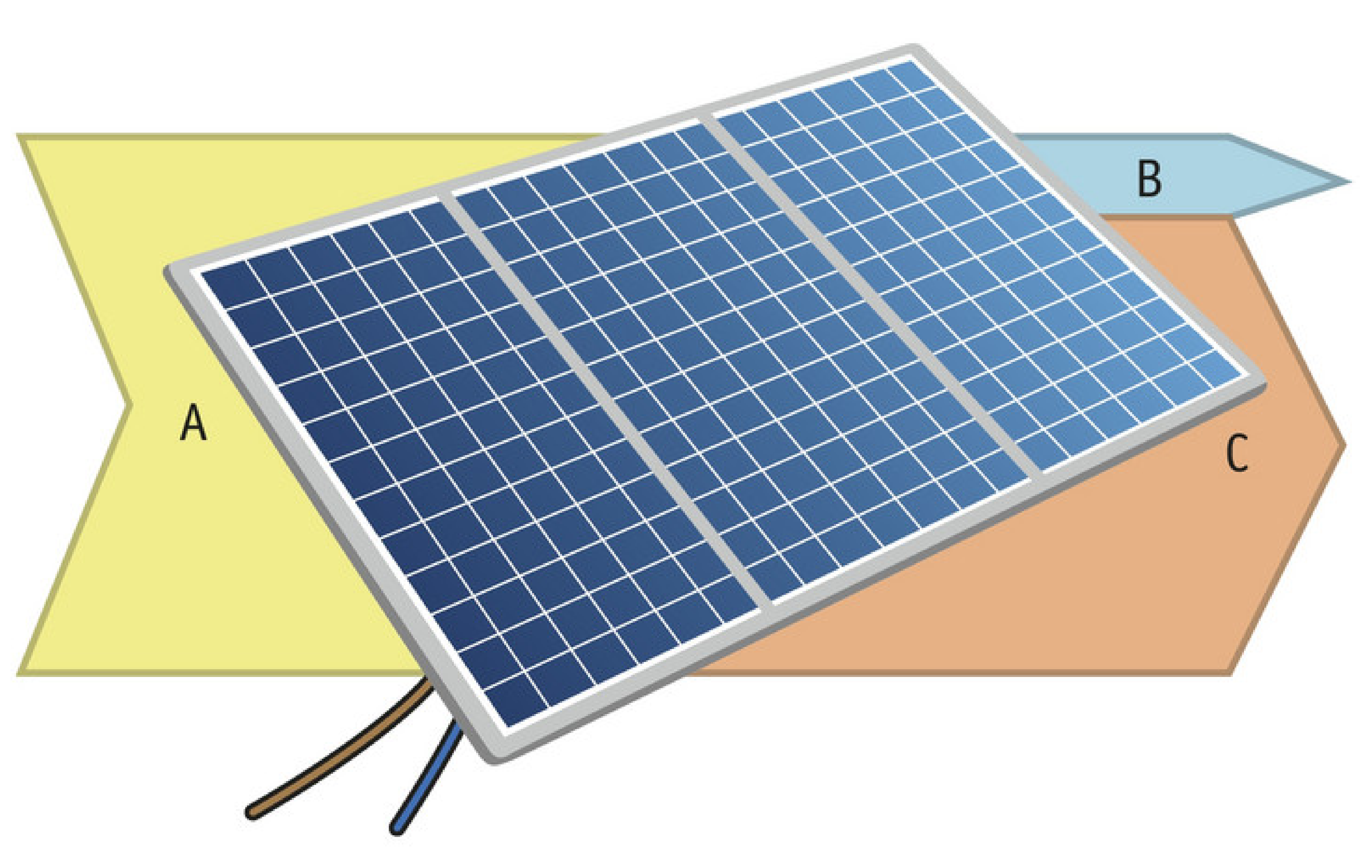
11 Radiator foil is shiny aluminium foil that can be applied on a wall behind a radiator (figure 41). This lets you reduce the heat loss through the wall.
What property of the foil reduces the heat loss?
A The foil conducts heat well.
B The foil does not let air or moisture through.
C The foil reflects infrared radiation.

A lot of heat is lost behind radiators, because this is where the temperature difference with the outside is highest. If you want to avoid that heat escaping through the wall, radiator foil is a good solution. The foil makes sure that the heat is kept inside and it will save you a lot of gas.

▲ **figure 41**
advertisement for radiator foil

12 In a gas burner, 2.5 L natural gas is burned. The calorific value of natural gas is 32 MJ/m^3.
How much heat is produced by the combustion of 2.5 L of natural gas?
A 80 kJ
B 104 kJ
C 128 kJ
D 80 MJ
E 104 MJ
F 128 MJ

13 Figure 42 is a sketch of the energy flow chart of a panel of solar cells. The efficiency of the panel is 15%.
What type of energy:
a is represented by arrow A?
b is represented by arrow B?
c is represented by arrow C?



▶ **figure 42**
the energy flow diagram for a solar panel

14 What measuring instruments do you need for determining the amount of energy used by an immersion heater? Choose between: *ammeter – measuring cylinder – scales – stopwatch – thermometer – voltmeter*.

15 Anjum is using an immersion heater to heat 200 mL water. The coil produces 18 kJ of heat in five minutes. Of that, 15 kJ is absorbed into the water.
Calculate the efficiency for heating the water.

16 Two bulbs give off the same amount of light. Bulb A has an electrical power consumption of 12 W and an efficiency of 20%. Bulb B has an electrical power consumption of *X* W and an efficiency of 25%.
Calculate or work out the value of *X*.

17 Georgina heats 200 g water from 15 °C for ten minutes using a heating element of 70 W.
Calculate the final temperature of the water.

18 In the Mojave Desert in the United States, there are various power plants that generate electricity using sunlight. Figure 43 shows you part of one of these power plants. The mirrors reflect sunlight onto tubes that are filled with oil. The hot oil is used to heat water up and produce steam.
- **a** Which energy conversion does this power plant have to carry out as efficiently as possible?
- **b** Why would this power plant have been built in the desert?
- **c** There are also disadvantages to building a power plant in the desert.
  State one.
- **d** Why would a solar power plant like this be more likely to get built in Algeria or Israel than in Sweden or the Netherlands?

▶ **figure 43**
a solar plant in the Mojave Desert

19 Heather is determining the efficiency of a gas ring at home that is used for boiling water. To do this, she starts with 1.2 L of water at 15 °C. She reads the gas meter at the beginning and end of the experiment. The initial value is 02345.620 m^3 and the final value is 02345.651 m^3.
Calculate the value that she is going to get for the efficiency.

20 The newspaper contains a report on an experimental electricity station that runs on waste wood (figure 44).
- **a** Calculate how many kWh of electrical energy this power station can supply in a day.
- **b** The annual consumption of an average Dutch household (of 2.2 people) is 3500 kWh of electrical energy.
  Calculate how many households this power station could supply with electricity.
- **c** Assuming that the calorific value of the briquettes is the same as wood, namely 16 MJ/kg, work out the efficiency of the power station.

There are 408 bulbs of 60 watts each shining on the panel, showing that the generator is working flat out, powered by a loudly humming gas motor. That is powered in turn by a high-energy gas mixture made from waste wood.
Every hour, the gasifier uses 80 kilograms of briquettes that are made of compressed wood shavings and sawdust. The gasification of the briquettes takes place at 1200 degrees on a fixed grille at the bottom of the reactor. The researchers keep a precise record of how much energy this generates.

▲ **figure 44**
an article about a waste wood plant

SPORT AND NUTRITION

Cyclists call it hitting the wall, or that they have encountered 'the man with the hammer'. A victim explains: "One moment you're absolutely flying and the next it's like riding through treacle. Your legs won't respond, there's a cold sweat on your forehead and your stomach's grumbling. You know that you have to eat something quickly, but just thinking about it makes you feel ill. The tank is empty. Absolutely empty..."

Endurance athletes, such as cyclists and marathon runners, learn to carefully manage the stored energy in their body. This is how they can avoid hitting the dreaded wall: an acute lack of energy that suddenly overwhelms the athlete. But how does such an energy crisis occur?

Fuel for the body

Humans can take their required energy out of three types of nutrients: carbohydrates, fats and protein. The body uses the chemical energy in these substances by burning them: a process similar to regular combustion, although there are no flames. Complete combustion provides:

- 1 gram carbohydrates: 16.8 kJ (4.0 kcal);
- 1 gram fat: 37.8 kJ (9.0 kcal);
- 1 gram protein: 16.8 kJ (4.0 kcal).

If you are sitting quietly in a chair, the consumption of fuel in your body – the respiration – is low and the body does not have a preference for any particular type of fuel. But if you put a lot of effort into doing sports, the fuel consumption shoots up at that point. The body then uses carbohydrates in particular, because that type of fuel can be used more efficiently than proteins or fats. People are able to build up a stock of spare carbohydrates by storing glycogen in the liver and muscles (see boxed text). The only problem is that the storage capacity is very limited. You are able to store about 600 grams of glycogen. That is not a huge amount: enough to keep you going for an hour and a half at most during intense sporting activity.

Once the stock of glycogen runs out, the body switches to burning fats and proteins. But because that process is less efficient, there is suddenly a lot less energy available: the 'man with the hammer' strikes mercilessly. If only you'd eaten something earlier...

Topping up the tank in time

Professional athletes and cyclists hardly ever 'hit the wall' now. They have learned to top up their

Glucose and glycogen

The digestible carbohydrates in your food (there are some indigestible ones too) are broken down into glucose in the gut. The blood absorbs the glucose and then transports it to every part of the body. Glucose is itself a carbohydrate, the preferred energy source for the muscles.
The body tries to keep the level of glucose in the blood constant. If there is too much glucose, it is converted into glycogen and stored in the liver and the muscles. That lets the body build up a store of rapidly available energy.
When your muscles have to work hard, they take up a lot of glucose. The blood glucose level then begins to drop. Your body responds to that straight away: the liver and muscles convert their glycogen back into glucose and release it into the blood. That is how the glucose concentration in the blood is kept at the right level.
If you keep the activity up without eating, the stocks of glycogen become exhausted. The blood glucose level then drops suddenly. The symptoms of this (fatigue, dizziness, nausea) are known as 'hitting the wall'.

glycogen reserves in time by eating and drinking properly. They do that the whole day long, even while they are racing.

A few numbers to give you an idea... Someone who is working at a desk and not exercising much can get by on about 10 MJ (2400 kcal) per day. A race cyclist in the Tour de France needs an average of 29 MJ (7000 kcal) per day – nearly three times as much. During the toughest Alpine stages, the energy requirement can get up to 38 MJ (9000 kcal) per day.

These figures are only averages; the cyclists are not all the same. But it should be clear that a lot of food is needed. The daily menu consists of a lot of grain products (pasta, bread and rice) and sweet foods, because those are chock full of carbohydrates. This is what a racing cyclist gets through on an average day in the Tour de France:

At breakfast, the glycogen 'tank' is topped up to the brim. Even so, a cyclist will have to eat regularly during the day's race. You cannot do a stage of 175 km just on your glycogen reserves, let alone have anything left to let you produce a sprint finish. The plastic bags of food that are handed out as they go are essential to the cyclists' performance.

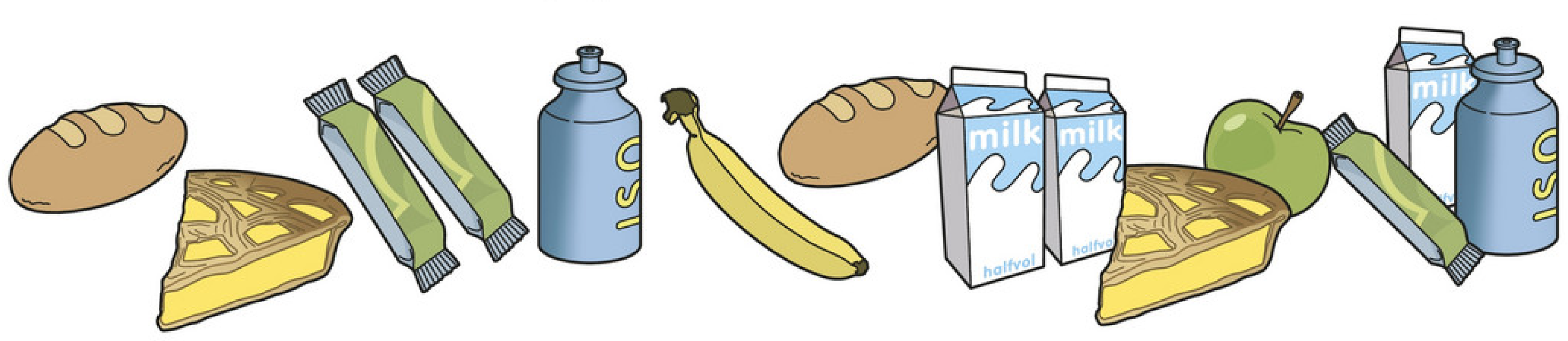
During the toughest Alpine stages, the energy requirement can get up to 38 MJ (9000 kcal) per day.

Being smart with energy

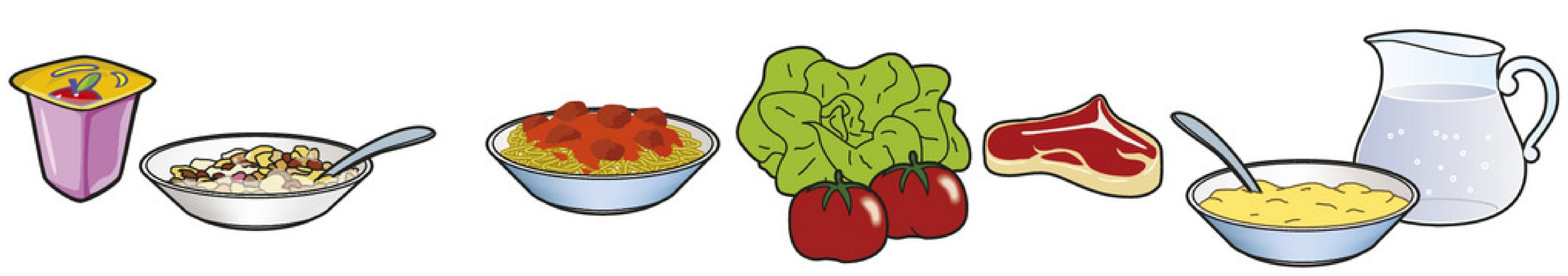
You can look at the combination of man plus bike as a kind of machine, with the cyclist himself as the engine. Just as with a car, techniques have been thought up for measuring the useful power output of that engine. The more power the cyclist is able to develop, the faster he will go – and the more energy he will consume. The power developed by a cyclist can vary a great deal during a stage, from about 150 W during a quiet section through to as much as 450 W as they struggle up a mountain. A genuine sprinter can in fact develop more than 1000 W of power in the sprint finish, although a high output like that can only be maintained for a few seconds.

A good sprinter saves his energy reserves by riding along quietly in the pack. Shortly before the finish, a 'train' of his team mates will help him get towards the front, and then he will wait for a moment behind the leader and finally sprint away. If he times it right, he will just have enough strength in his legs to go flat out to the finishing line – a question of managing the energy well, like so much of race cycling.

Breakfast: one litre fruit juice, eggs, white rice, ham, cheese, cereal, honey, bread with butter, marmalade and yoghourt. Total 6.3 MJ.



The cyclist eats twice on the way: whole grain rolls, cake, energy bars, fruit, and lots of fluids. Every hour he drinks half a litre of water or an isotonic drink to supplement the salt his body loses through perspiration. Every now and then he drinks liquid glucose. Total 12.2 MJ.



After the race the cyclist eats a plate of cereal with yoghourt. Dinner consists of a plate of pasta, salad, meat, mashed potatoes and water. Total 10.5 MJ.

Exercises

1 The figure on the right shows you part of the packaging of crispbread.
  a Does crispbread suit the diet of an endurance athlete? Explain.
  b Calculate the energy value of 100 grams of crispbread using the data in the text.
  c Compare your answer to the energy value listed on the label. What do you notice?

Nutritional value	per 100 g	per piece
Energy kJ/kcal	1320/310	165/39
Proteins	10.0 g	1.3 g
Carbohydrates	64.6 g	8.1 g
of which sugars	1.4 g	0.2 g
Fats	1.5 g	0.2 g
of which saturated	0.4 g	0.1 g
of which monounsaturated	0.2 g	< 0.1 g
of which polyunsaturated	0.5 g	0.1 g
Dietary fibre	15.5 g	2.0 g
Sodium	0.4 g	50 mg

Contents: rye crispbread, approx. 20 pcs
Ingredients: whole rye flour, yeast, salt

2 A cyclist who escapes the peloton on his own almost always gets caught by the peloton during a flat stage.
  a Why is it so difficult to keep out of the clutches of the peloton? Use the term ‘power’ in your explanation.
  b How is it possible that escapes during mountain stages are successful more often?

***3** For an experiment in a sports centre a professional cyclist cycles on a cycle ergometer for exactly one hour. Measurements show that he uses 1425 kcal of chemical energy in that hour. His effective output during the hour is an average of 385 W.
Use this data to calculate the efficiency of the cyclist.

5

Forces and motion

Traffic safety

Mobility is very important in our society. Traffic on the roads and railways, in the air and on the waterways is getting heavier and heavier, and safety must of course never be compromised.

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1 Accelerating

▲ figure 1
A car driver looks regularly at the speedometer.

The aircraft you fly in to go on holiday has a cruising speed of more than 900 km/h. The carriages of a roller coaster 'only' have a maximum speed of perhaps 150 km/h. Yet a ride in a roller coaster feels much more exciting than a flight in an aircraft. This is because the carriages accelerate very quickly. Apparently it is not actually the speed itself that you feel in your stomach, but the change in speed.

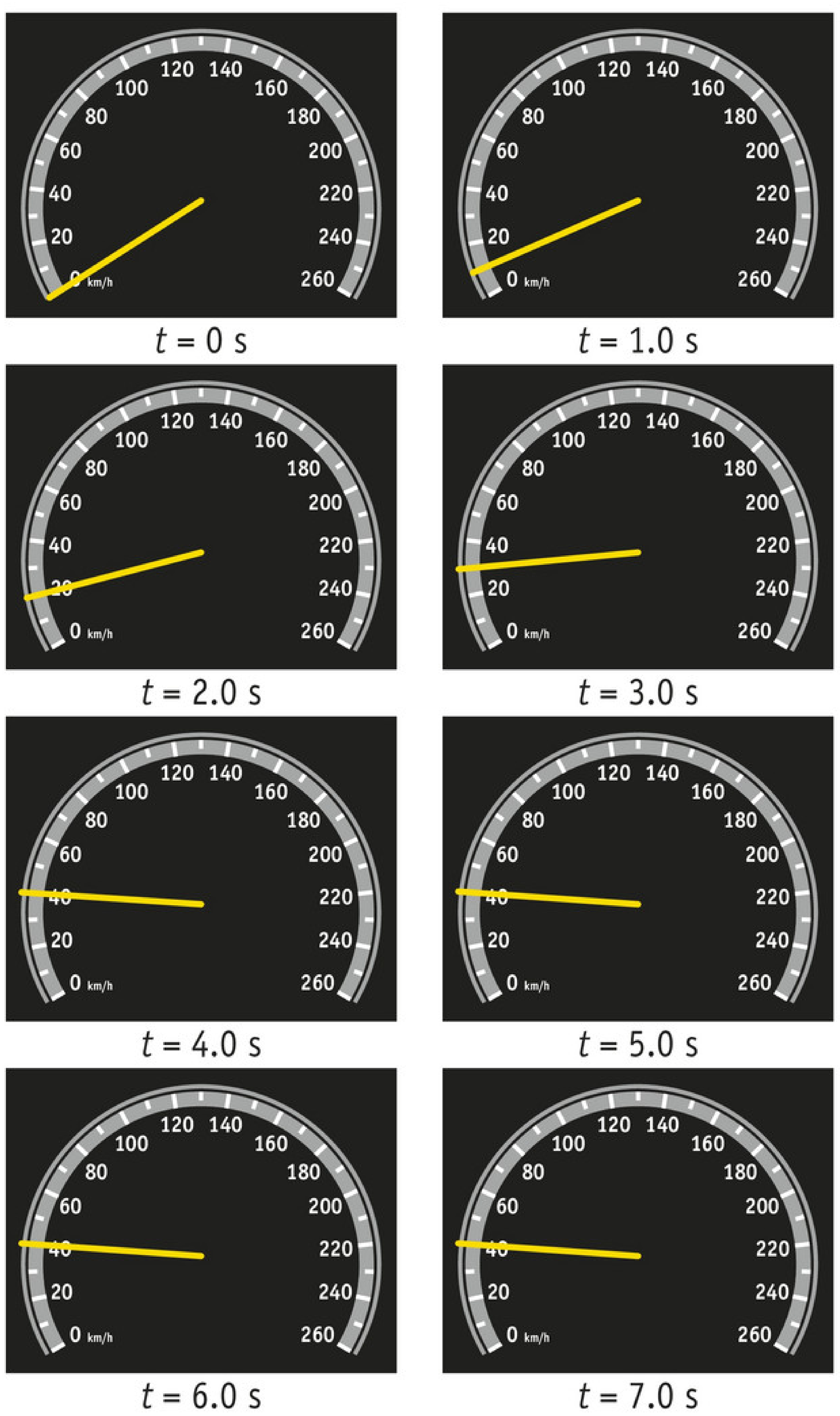
Making a (*v*,*t*) diagram

The speedometer of a car shows how fast the car is driving at any particular moment (figure 1). If you photographed the speedometer at intervals of 1 second, you would get a series of images such as shown in figure 2. From the graph, you can read the speed at times t = 0 s, t = 1.0 s, t = 2.0 s, etc.

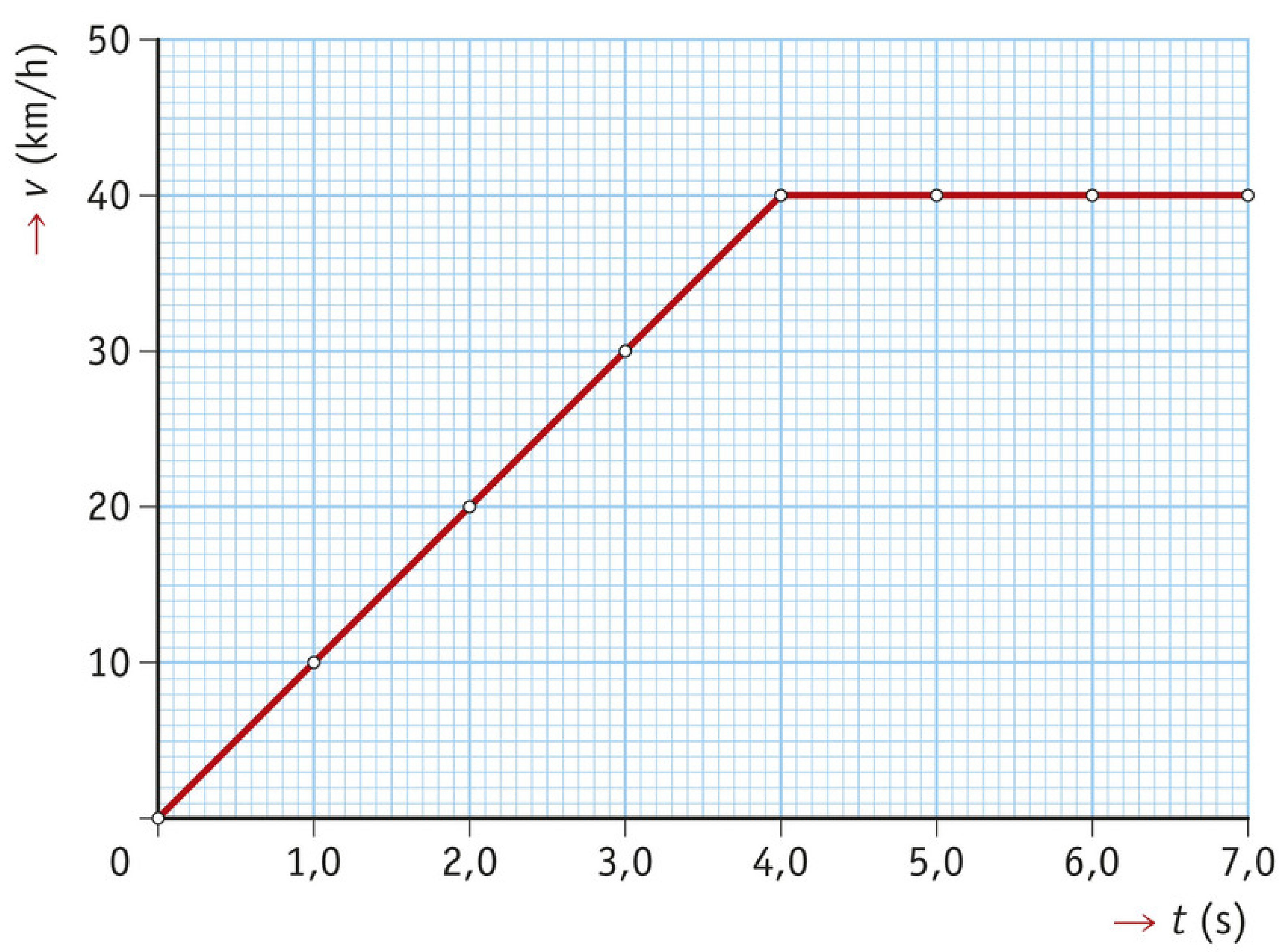
The **(speed, time) diagram** in figure 3 was drawn using the data from figure 2. A graph like that shows you at a single glance how the entire motion progressed. A (speed, time) diagram is often called a **(*v*,*t*) diagram**. The time t is shown along the horizontal axis and the speed v along the vertical axis.

The diagram shows what the speed is at any moment of the motion.

- From t = 0 s to t = 4.0 s, the motion is an **acceleration**. The car starts to move at t = 0 s and then speeds up gradually. This means that its speed is increasing.
- By t = 4.0 s, the car has reached the speed that the driver wants to go at, 40 km/h. After that, the speed of the car does not change any more. A motion during which the speed is constant is called a **uniform** motion.



▲ figure 2
The speedometer shows you how fast the car is going.

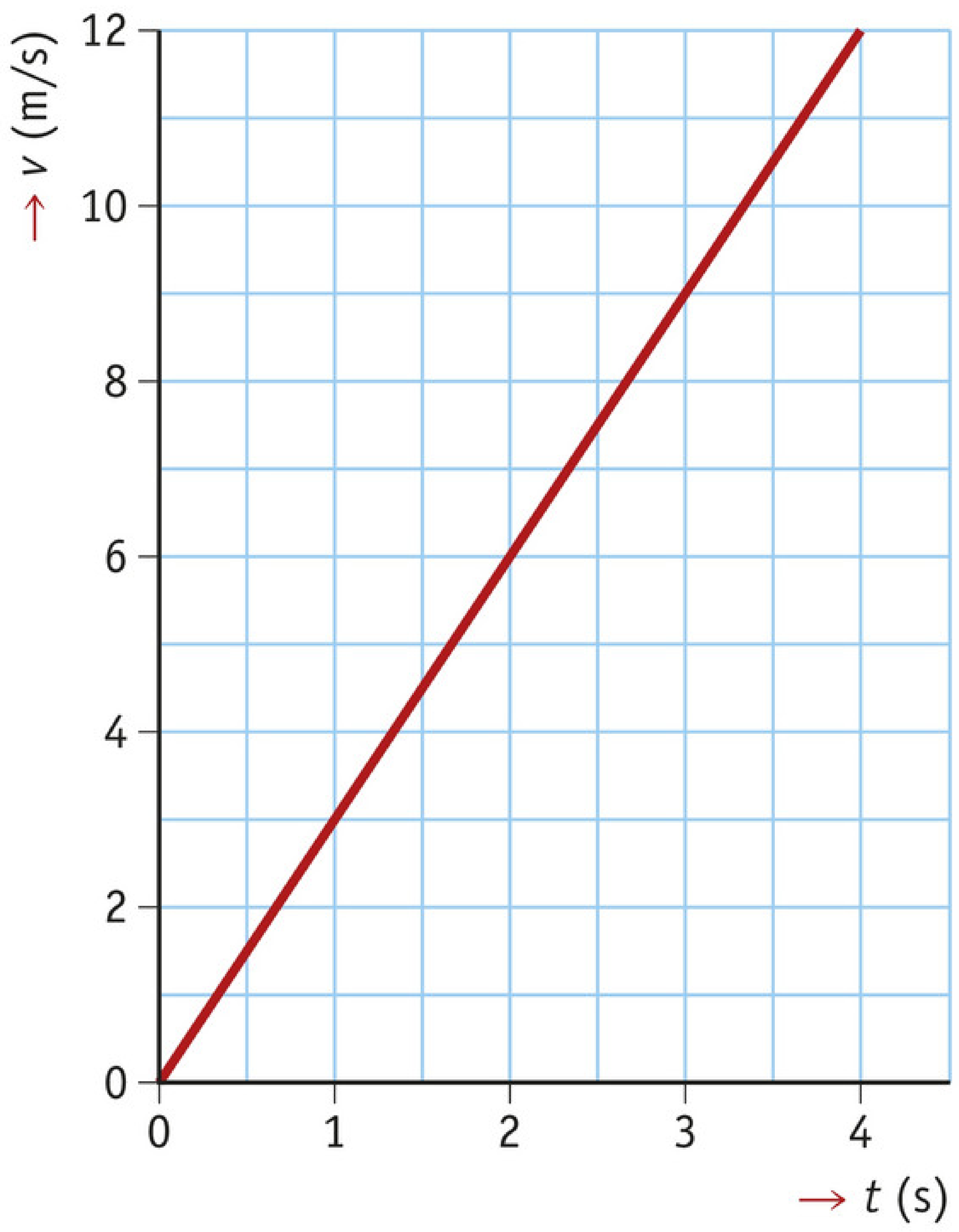


◀ figure 3
the (*v*,*t*) diagram of an accelerating car

Make sure that you do not confuse a (v,t) diagram (speed against time) with an (x,t) diagram (position against time). You should always look first at the quantities (x or v) and units (m or m/s) that are given along the axes. You can use them to tell what type of graph it is.

Uniformly accelerated motion Experiment 1

Figure 4 shows part of the (v,t) diagram in a test report on a car. You can see that the speed increases uniformly for the first four seconds, the graph is a straight line. A motion in which the speed keeps increasing at a steady rate is called a **uniform acceleration**.



▲ **figure 4**
This is how the test car accelerates as it is driven away.

After one second the speed is 3 m/s, after two seconds 6 m/s, after three seconds 9 m/s, and so on. In other words, the speed is increasing by 3 m/s every second. The change of speed per second is called the **acceleration**. In the motion in figure 4, the acceleration is 3 m/s per second. This is written as 3 m/s², and you say "three metres per second squared" or "three metres per second per second".

The symbol for acceleration is the letter a. So this is how you write the acceleration: $a = 3\ \text{m/s}^2$. This means that the speed is increasing by 3 m/s every second.

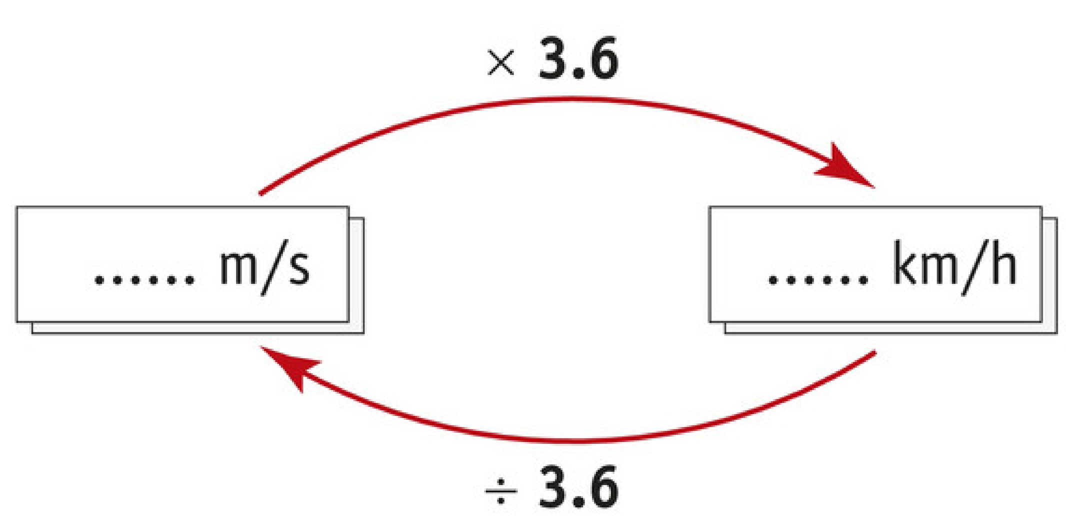
Calculating the acceleration

In a uniform acceleration, the speed increases uniformly from the initial speed v_i to the final speed v_f. You can calculate the change in speed Δv by subtracting the initial speed from the final speed: $\Delta v = v_f - v_i$.

In order to calculate the acceleration, you divide the change in speed Δv by the time it took Δt. This gives you the change in speed per second:

$$a = \frac{\Delta v}{\Delta t}$$

Speeds are often expressed in units of kilometres per hour (km/h). In order to be able to calculate the acceleration, you need to convert the speed given into units of metres per second (m/s). A speed of 90 km/h, for example, is 90 ÷ 3.6 = 25 m/s (figure 5).



▶ **figure 5**
How to convert from m/s to km/h and vice versa.

Worked example 1
A car wants to overtake a lorry on the motorway. The driver presses the accelerator down and the car accelerates uniformly for 4.0 s. As a result, the speed increases from 54 km/h to 90 km/h.
Calculate the acceleration.

data $v_i = 54$ km/h = 15 m/s
$v_f = 90$ km/h = 25 m/s
$\Delta t = 4.0$ s

required $a = ?$

working $\Delta v = v_f - v_i = 25 - 15 = 10$ m/s

$$a = \frac{\Delta v}{\Delta t} = \frac{10}{4.0} = 2.5 \text{ m/s}^2$$

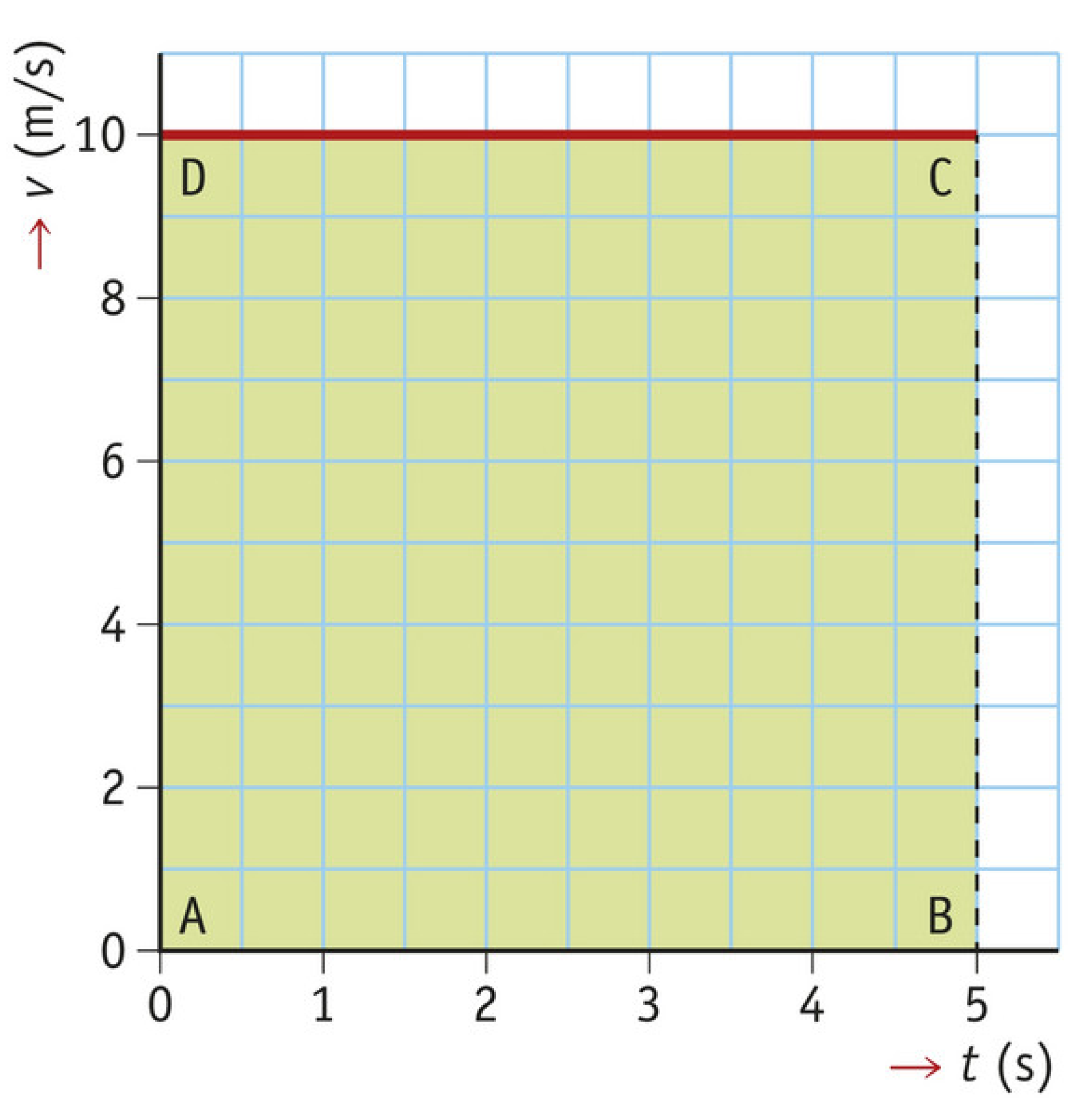
So the speed of the car is increasing by 2.5 m/s every second (= 9.0 km/h).

Determining the distance covered

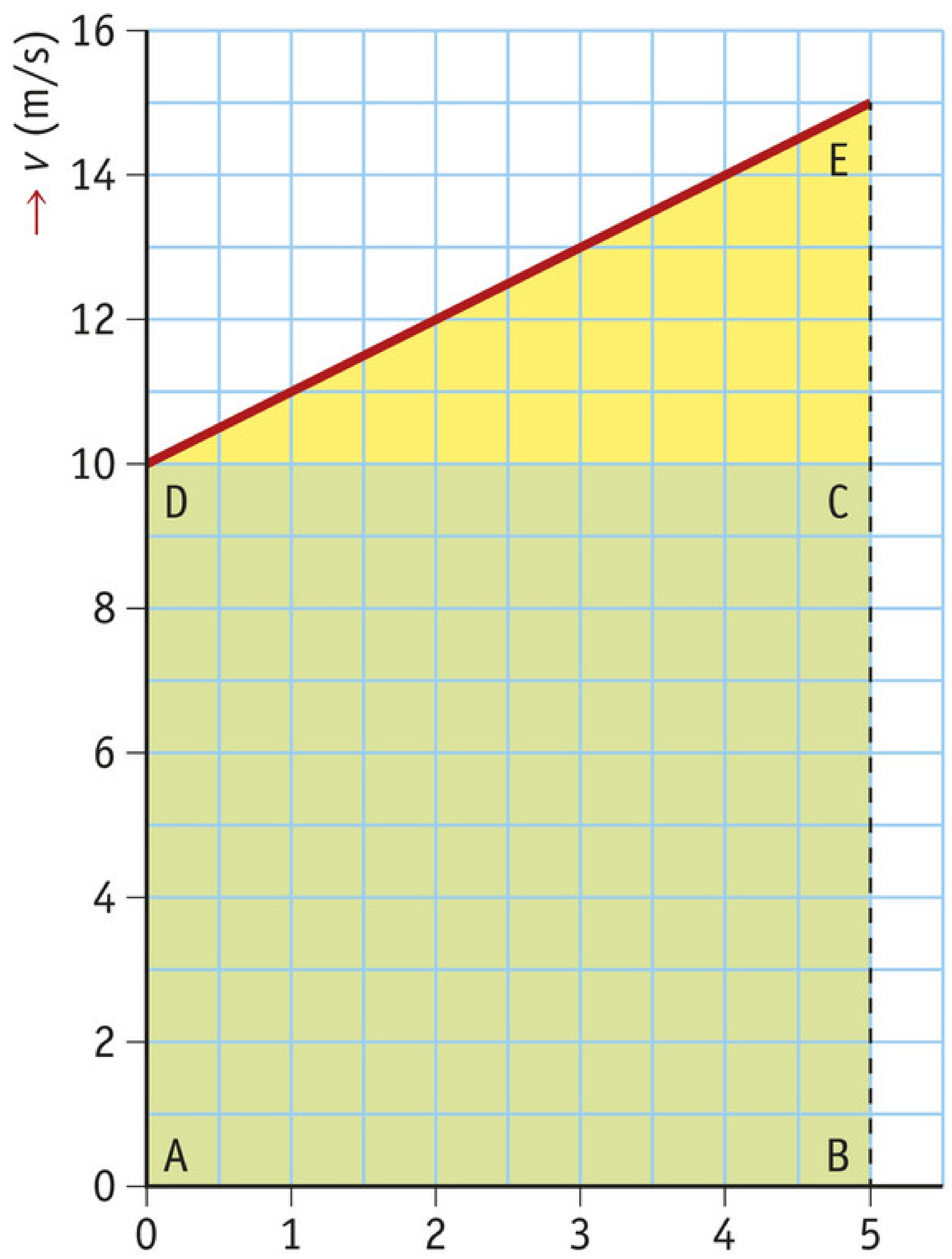
When a car accelerates, it will cover a certain distance during that motion. You can determine the distance covered by looking at the (v,t) diagram of the motion. In this case it means that you can calculate the distance using the graph.

Figure 6 shows you the (v,t) diagram of a cyclist who is moving uniformly, at a (constant) speed of 10 m/s. The distance that the cyclist has covered after 5.0 s can be calculated as follows: $s = v \cdot t = 10 \times 5.0 = 50$ m. This is equal to the area under the (v,t) diagram = the area of rectangle ABCD.

You can also find the distance covered in a uniform acceleration by determining the area under the curve – or just a line in this case – of the (v,t) diagram.



◀ **figure 6**
the (v,t) diagram for a uniform motion



▲ **figure 7**
the (v,t) diagram for a uniform acceleration

Worked example 2
Figure 7 shows you the (v,t) diagram of a skier who is accelerating uniformly from 36 km/h (10 m/s) to 54 km/h (15 m/s) in 5.0 s. Determine the distance that the skier covers.

data
v_i = 36 km/h = 10 m/s
v_f = 54 km/h = 15 m/s
t = 5.0 s

required
s = ?

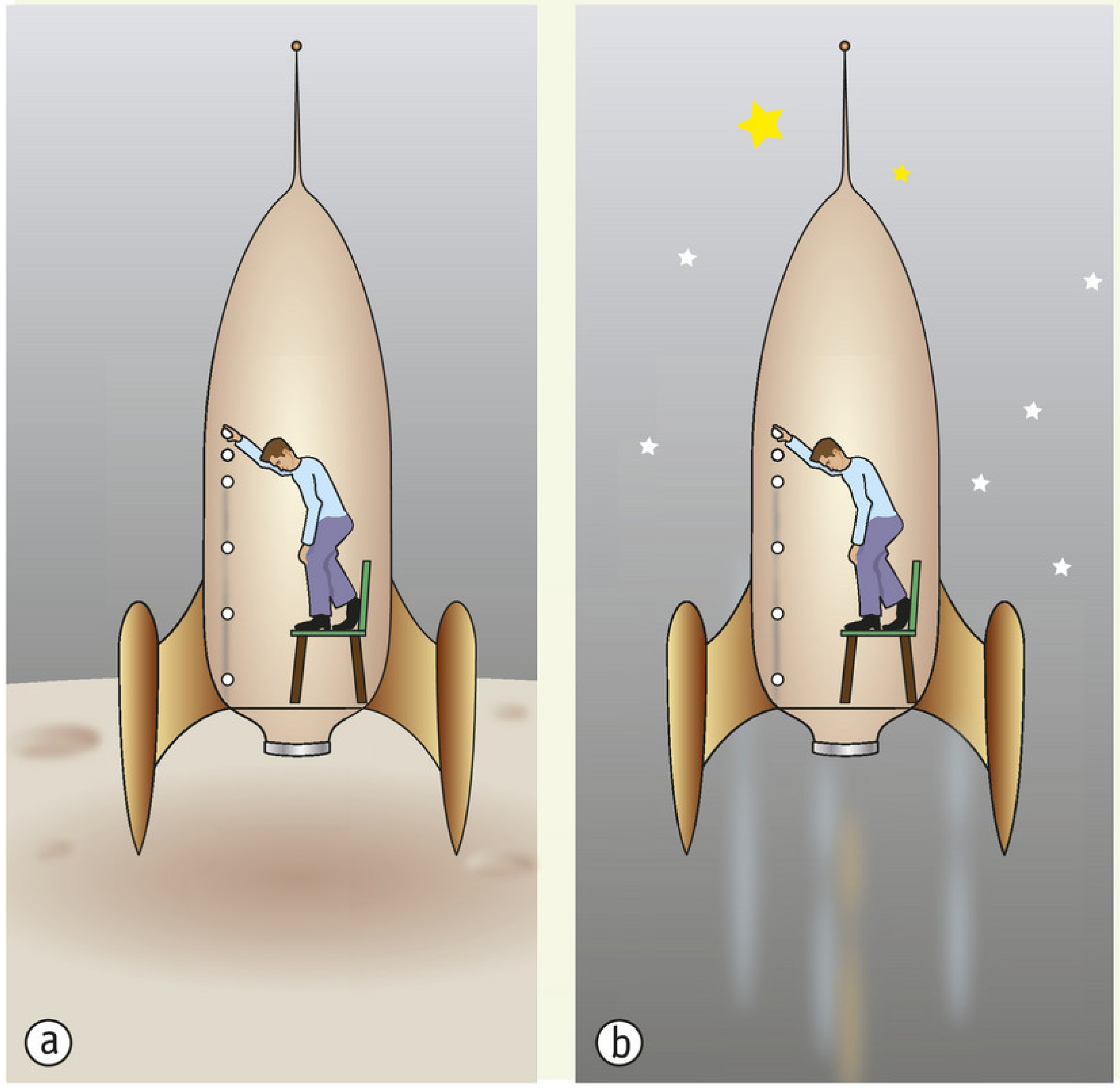
working
The distance covered is the area under the curve of the (v,t) diagram:
s = area of rectangle ABCD + area of triangle DCE
= 5 × 10 + ½ × 5 × (15 − 10) ≈ 63 m

So the skier covers a distance of 63 m.

Plus Gravity as acceleration

At the beginning of the twentieth century, Albert Einstein published his theory of general relativity. That theory is based on a famous thought experiment that Einstein came up with. Imagine that you are in a lift that is moving towards the Earth in free fall. You would then float around in the lift cabin because the lift is falling at the same speed as you are. As long as you do not look outside, there would seem to be no gravity.

▼ **figure 8**
It makes no difference where you carry out an experiment: on the Earth (a) or in a spaceship that is accelerating at 9.8 m/s² (b).



Einstein imagined what would happen if a lift in a free fall suddenly began accelerating. It would then seem as if gravity was suddenly switched on. Everything around you would then have a weight again. It makes no difference whether you are on Earth where the free-fall acceleration is 9.8 m/s² or in a lift that is accelerating at a rate of 9.8 m/s², things will behave in exactly the same way in both situations (figure 8).

Einstein concluded on the basis of this thought experiment that you cannot distinguish between the effects of acceleration and gravity. This 'principle of equality' is one of the cornerstones of the theory of general relativity. Nowadays you could also test this idea in a spacecraft, a modern variant of Einstein's lift.

Exercises

1 Answer the questions below.
a What do you call a motion:
- where the speed is increasing uniformly?
- where the speed stays the same all the time?

b What formula can you use to calculate the acceleration of a moving object?
c What is meant by the statement that the acceleration of the object is 3 m/s^2?
d How can you determine the distance covered using the (v,t) diagram of a motion?

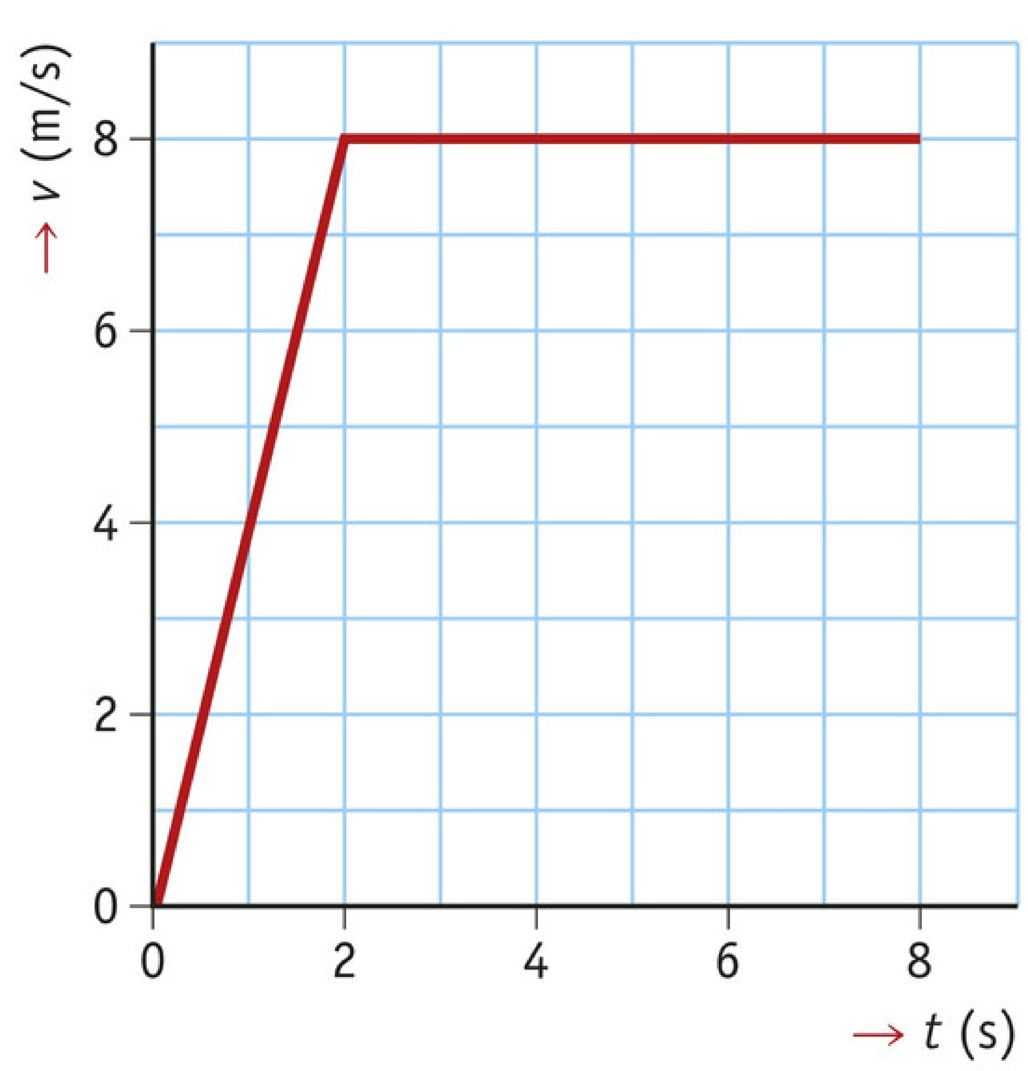
2 Copy table 1 and complete it.

▼ **table 1** various variables and their units

variable	symbol	unit	symbol
distance			m
		second	
			m/s
	a		

3 Draw the (v,t) diagram of:
a a speed-skater who does a 40 s lap on the skating rink at a constant speed of 36 km/h.
b a ski-jumper who goes down a ski jump under a uniform acceleration. When he leaves the ski jump after 12 s, his speed is 90 km/h.
c a car driver who accelerates from 63 to 81 km/h in 3.0 s during an overtaking manoeuvre.

4 Figure 9 shows you the (v,t) diagram of Wendy on her scooter.
a Calculate Wendy's acceleration during the first 2.0 s.
b Determine the distance that Wendy covers in the first 8.0 s of her journey.



▲ **figure 9**
Wendy's (v,t) diagram

5 A car is driving at a speed of 63 km/h. The car driver puts his foot down so that his speed increases to 90 km/h in 5.0 s.
a Calculate the car's acceleration in m/s^2.
b Determine the distance that the car covers during the motion. To do this, first draw the (v,t) diagram.
c Calculate the final speed if the acceleration takes 6.0 s instead of 5.0 s.

6 An aircraft accelerates from 0 to 310 km/h in 50 s and then takes off. A sports car accelerates from 0 to 100 km/h in 15 s.
Do a calculation to show in which situation the (average) acceleration is the highest.

Acceleration, not speed, makes a cheetah a great hunter

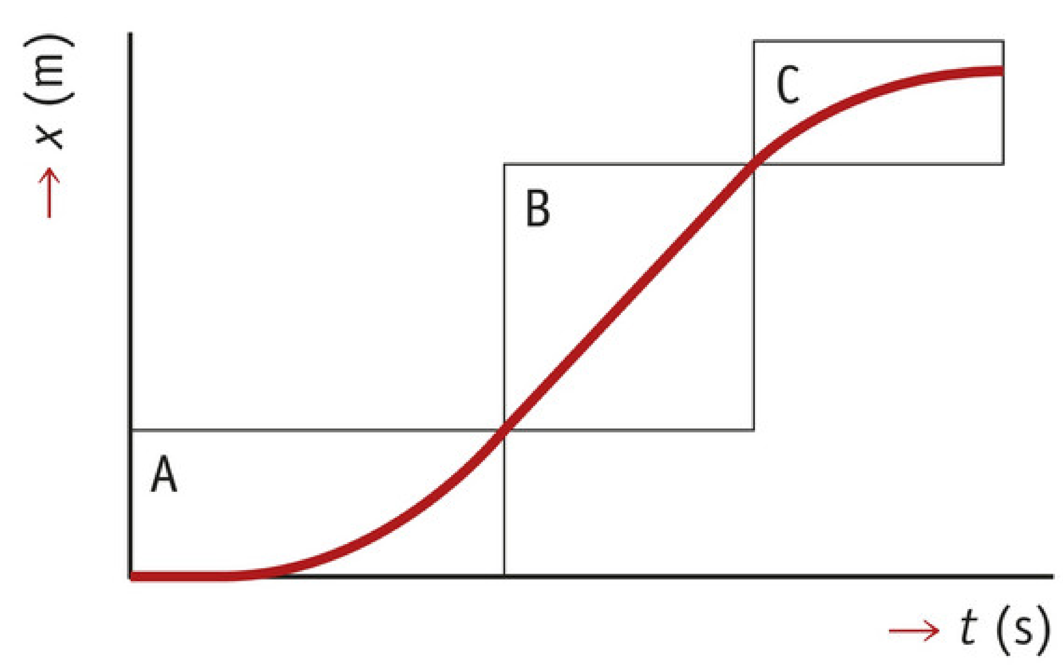
The cheetah rarely reaches the top speed (27 m/s) for which it is famous. However, the animal has a fantastic acceleration and is extremely manoeuvrable. British scientists measured the speed of cheetahs in the wild and found an average top speed of 'only' 14.9 m/s. In comparison, a top human sprinter reaches 12 m/s.
However, the animals have another great advantage during the hunt: their muscles can contract extremely quickly. In a single stride, they can accelerate by 3 m/s or decelerate by 4 m/s. They always decelerate just before changing direction. This lets them corner much more sharply.

▲ **figure 10**
an article about cheetahs

***7** Worked example 2 can also be done using the average speed during the acceleration. You then make use of the following formula for the distance covered s: $s = v_{average} \cdot t$.
Show that this method gives the same answer.

8 Read the newspaper article in figure 10.
- **a** Calculate the top speed of the cheetah in km/h.
- **b** The text says that the cheetah's speed increases by 3 m/s each stride. Explain how many strides the cheetah needs as a minimum to achieve a top speed of 27 m/s.
- **c** Measurements showed that one stride of a cheetah takes 0.45 s. Calculate the cheetah's acceleration.

***9** Figure 11 gives the (x,t) diagram for a sprinter in a race.
- **a** What type of motion does the sprinter have (uniform, accelerated or decelerated):
  - in part A of the motion?
  - in part B of the motion?
  - in part C of the motion?
- **b** Explain whether the average speed in part B is higher or lower than the average speed in part C, or exactly the same.
- **c** In the first 2.0 s, the sprinter ran with a constant acceleration of 4.0 m/s².
  Calculate the speed that the sprinter had reached after those 2.0 s.



◀ **figure 11**
the (x,t) diagram of the sprinter

Plus Gravity as an acceleration

10 An astronaut is in a spacecraft, far away from the stars and planets and is moving at a constant speed through space.
- **a** Explain why the astronaut is floating in the cabin.
- **b** Suddenly the spacecraft starts accelerating.
  Explain how the astronaut will notice this.

11 According to the theory of relativity, no object can ever be accelerated beyond the speed of light (300,000 km/s). Imagine that an average car could accelerate to this speed at an acceleration of 4.0 m/s².
Calculate how many days it would then take for the car to reach the speed of light.

2 Driving forces and resisting forces

If you have the wind against you while you are cycling, you will only move forward relatively slowly. Cycling also takes a great deal of effort when there is a lot of snow on the road. The forces that are working against your forward motion are stronger than usual.

Driving forces and resisting forces

When you cycle, your muscles provide the driving force that is needed for you to move forwards. If you stop pedalling, your speed immediately starts to drop. This is because there are various forces acting upon you and your bicycle to slow down the motion. The two most important ones are **air friction** and **rolling friction**.

The air friction occurs because you have to keep pushing the air in front of you aside. The faster you are going, the more resistance from air friction there is. You can reduce the air friction by making yourself more streamlined and by bending forwards on your bike (figure 12). You do not then have to push so much air aside because your **frontal cross-section** – your surface area as seen from the front – is smaller.

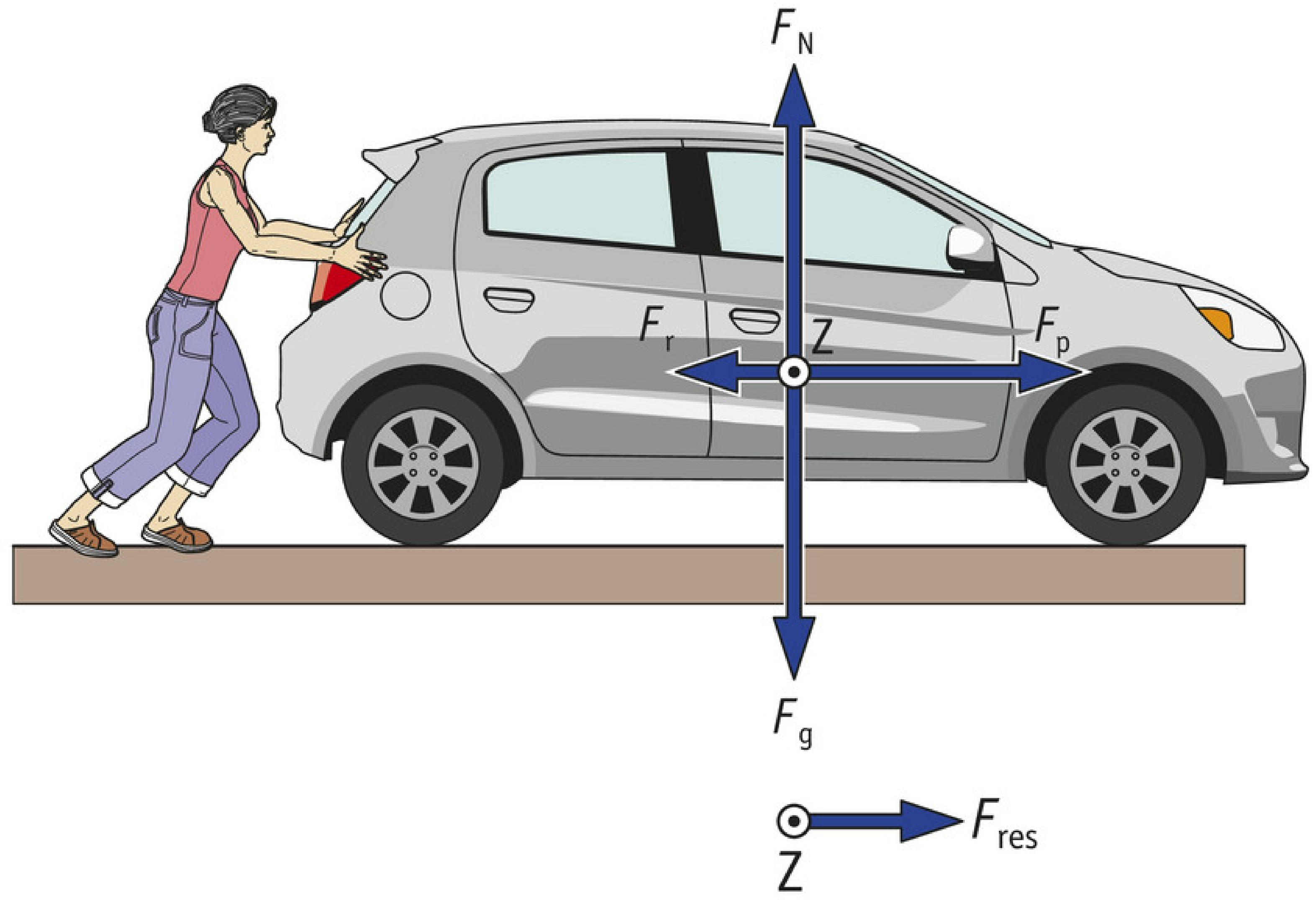
▲ figure 12
a streamlined racing cyclist

The rolling friction occurs because the tyres and the road surface are being made to change shape as you go along. The greater this deformation, the more rolling friction there is. You will notice this in particular if you have to ride through soggy sand. Roads and cycle paths therefore have a flat and hard surface. You can also reduce rolling friction by pumping your tyres up really hard.

The resultant

Figure 13 shows you a car that is being pushed from a standing start. There are four forces acting on the car: gravity F_g, the normal force F_N, the pushing force F_p and the friction F_r. These forces all act at different places, but in this figure they have all been shown acting on the centre of gravity Z. That makes it easier to determine the resultant force F_{res}.

As you can see in figure 13, the force due to gravity and the normal force cancel each other out, they are the same size but in opposite directions. The pushing force and the friction force also act in opposite directions, but they do not balance out – the pushing force is clearly greater than the resistance due to friction. This means that there is a resultant that acts to the right (in the direction the car is being pushed).



▶ **figure 13**
four forces and their resultant

The resultant changes the speed Experiment 2

If you only push the car gently, the resisting forces will be exactly as large as the push. The resultant is then zero. In that case, the car will not move.

If you keep pushing harder, the counteracting forces will also become larger. There will be a point where the resisting forces (F_r) can no longer compensate for the driving force (F_p). The resultant will then be greater than 0 N. As a result, the car will start to move faster and faster in the direction of the resultant (figure 14).

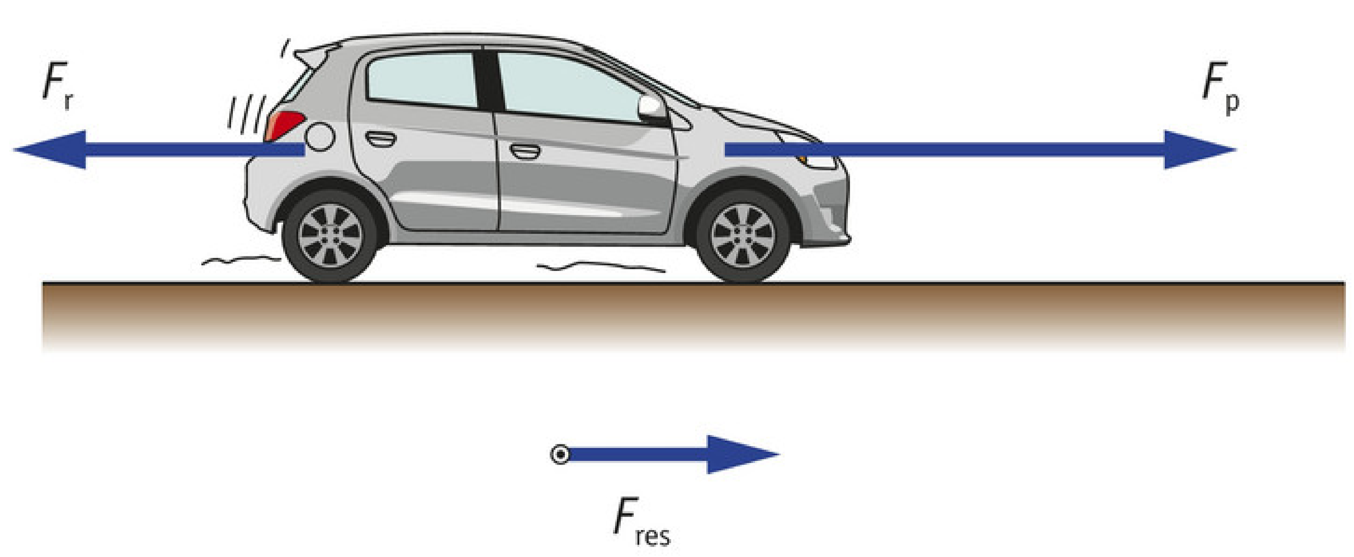
- When the driving force on an object is greater than all the resisting forces combined the object will accelerate.

Once the car has reached the desired speed, you push less hard. The driving force and the resisting forces (friction) are then equal again. The resultant is 0 N once again and the car will continue at constant speed (figure 15).

- When the driving force on an object is the same as all the resisting forces combined the object's speed will not change.

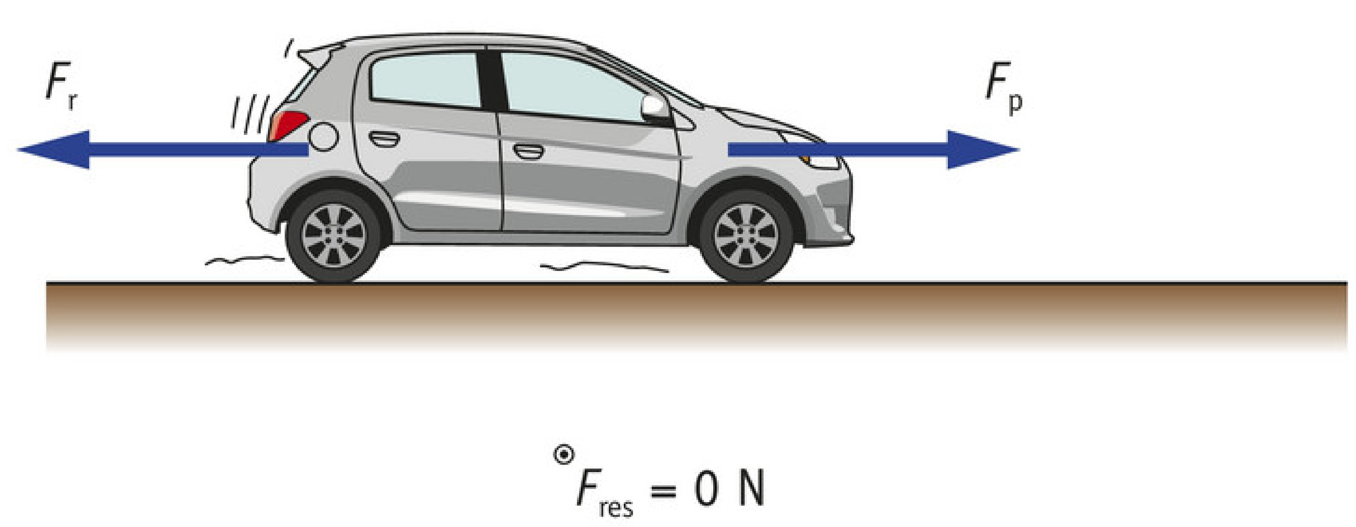
In other words, if the resultant force on an object is 0 N and the object is already moving, it will continue to move at the same speed. If the object is not moving, it will remain stationary.

This rule is also known as Newton's First Law.



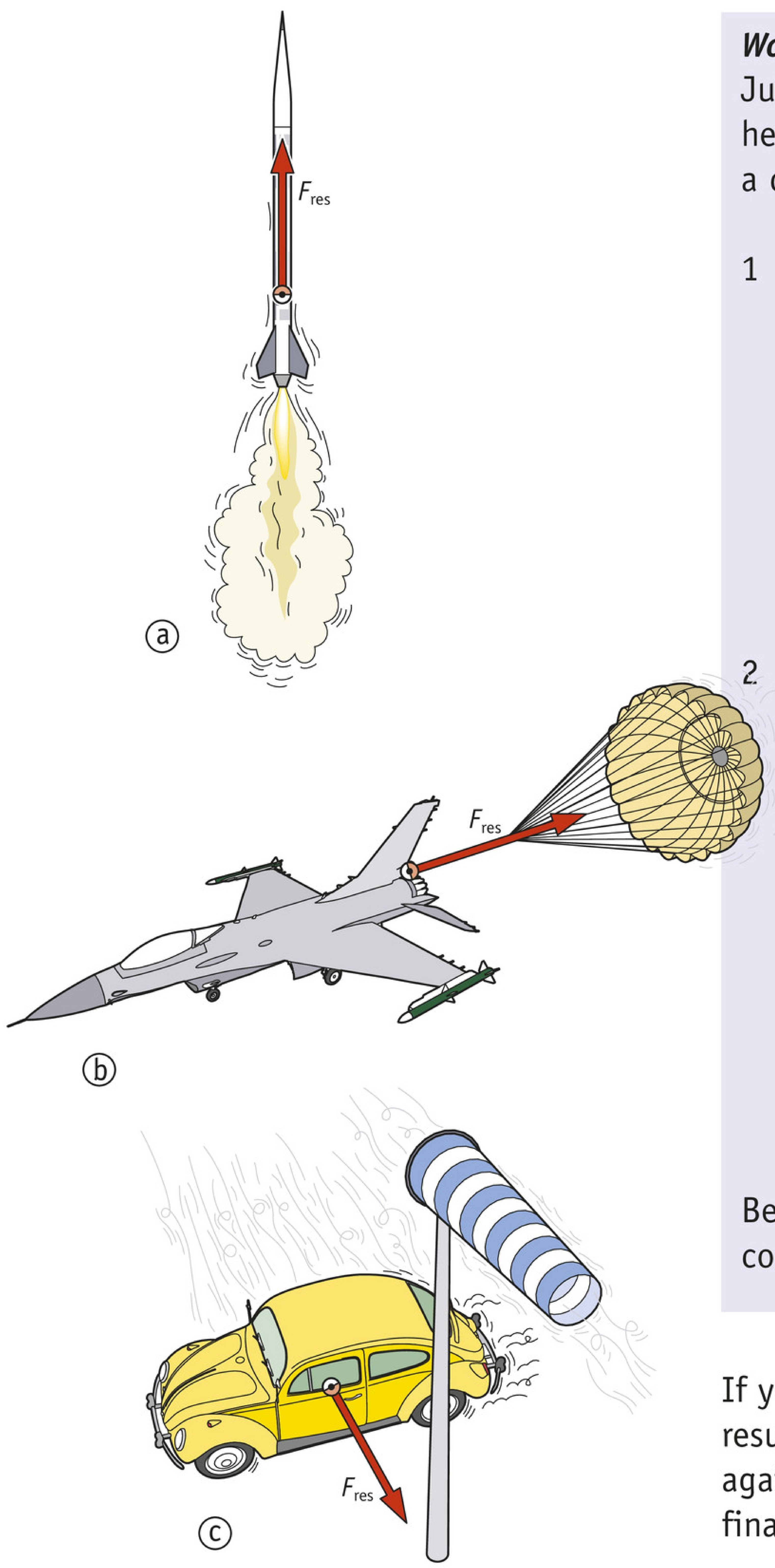
The car accelerates: the resultant is acting in the same direction as the direction of motion.

▲ **figure 14**
$F_{res} > 0$: the car accelerates.



The car goes at a constant speed: the resultant is 0 N.

▲ **figure 15**
$F_{res} = 0$: the car's motion is uniform.



▲ **figure 17**
The rocket is accelerating, the plane is decelerating and the car is changing direction.

Worked example 3
Julian is cycling to school at a constant speed along an exposed road, heading right into the wind. The driving force (F_p) applied to his bike is a constant 30 N.

1 Calculate the friction force.

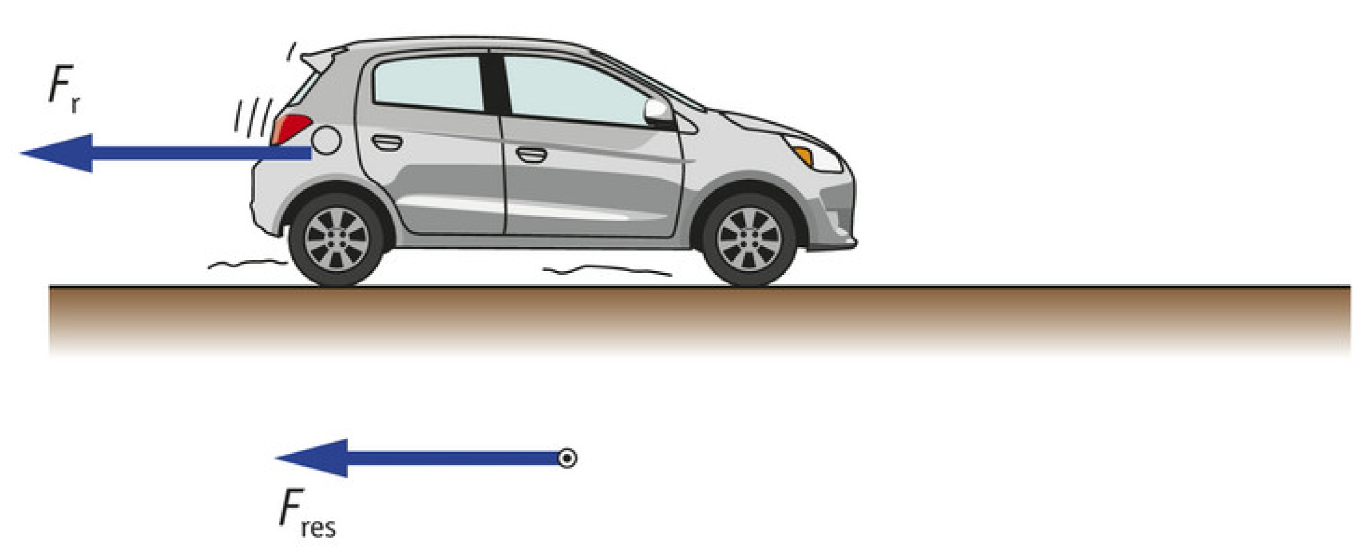
data	F_p = 30 N
required	F_r = ?
working	The resultant is 0 N because Julian is moving at a constant speed. So $F_r = F_p$ = 30 N.

2 The wind suddenly dies down, so that the overall friction force drops to 20 N.
Calculate the size of the resultant force on Julian now. Explain what effect this will have on Julian's motion.

data	F_p = 30 N F_r = 20 N
required	F_{res} = ?
working	The resultant is $F_{res} = F_p - F_r$ = 30 N − 20 N = 10 N.

Because the driving force is now greater than all the resisting forces combined, Julian's speed will increase: he accelerates.

If you stop pushing a little later, only the resisting forces will remain. The resultant is then the same size as all the resisting forces combined, acting against the direction of motion (figure 16). The car then slows down and finally comes to a stop.



The car decelerates: the resultant is acting against the direction of motion.

▶ **figure 16**
F_{res} < 0: the car decelerates.

– When the driving force on an object is less than all the resisting forces combined the object will decelerate.

The resultant makes the direction change

The resultant makes the object accelerate if it is acting in the same direction as the motion, as in figure 17a. It makes the object decelerate if it acts in the opposite direction to the motion, as in figure 17b. However, the resultant can also make a moving object change direction. For example, that happens if a sudden gust of wind comes from the side.

If the resultant is perpendicular to the direction of motion, as in figure 17c, then only the direction of motion changes, the object's speed is unchanged. If the resultant makes any other angle with the direction of motion, then both the speed and the direction of motion will change.

Plus Skydiving

Skydiving is a popular sport in which people jump out of an aeroplane and then have a long 'free' fall down. They then open their parachutes and float down to the ground at a much lower speed. In most jumps, the free fall lasts for about a minute.

During the free fall, the skydivers often do all sorts of exercises. Depending on the jumper's body posture, speeds can be achieved of 180 to over 300 km/h. The maximum speed is achieved when the skydiver is falling head first.

By changing the shape of the body, the skydiver can increase or decrease the air resistance. In the frontal position (figure 18), the parachutist is making the body area as large as possible. This maximises the air resistance acting upon him. In this position, the terminal velocity is about 180 km/h.

◀ **figure 18**
a skydiver in the frontal position

Exercises

12 Answer the questions below.
- **a** What creates the air resistance and the rolling friction when a car is moving?
- **b** How can cyclists reduce the air friction forces acting on their body?
- **c** Why might a racing cyclist pump the tyres of his bike as hard as possible?
- **d** What does Newton's First Law say about an object that is already moving?

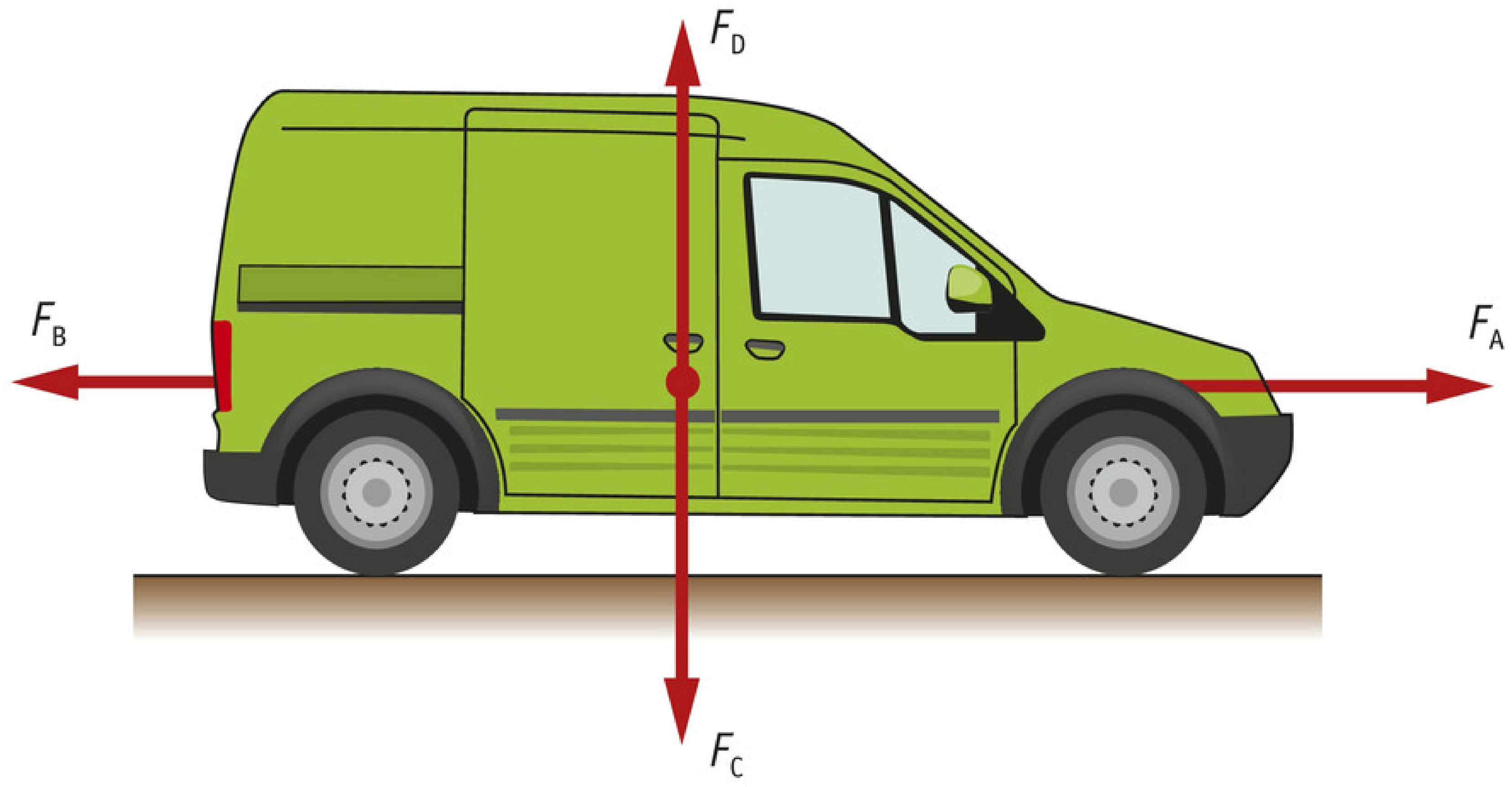
13 Describe the motion of an object:
- **a** if the resultant is acting in the direction of motion.
- **b** if the resultant on the object is 0 N.
- **c** if the resultant is acting against the direction of motion.
- **d** if the resultant is perpendicular to the direction of motion.

14 During a démarrage (an attempt by a racing cyclist to get away from the pack), a cyclist accelerates over a short period from 45 to 68 km/h. Explain whether the size of the forces resisting the movement are changed by this, and if so how.

15 Mary-Lou is pulling her friend along through the snow on a sledge. She pulls with a force of 50 N. The sledge moves through the snow at a constant speed of 4 km/h.
- **a** What force in particular is working against this motion?
- **b** How big is the resultant force acting on the sledge?

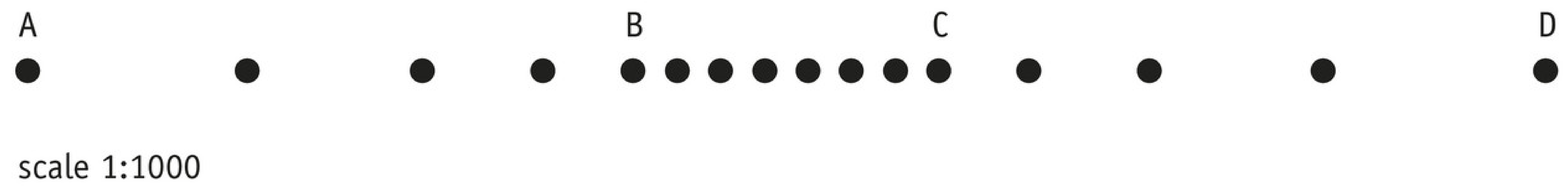
16 A removals man exerts a (horizontal) force of 600 N on a chest, but the chest does not move.
- **a** How big is the friction force while the removals man is pushing?
- **b** How big is the friction force if the removals man stops pushing?
- **c** When the removals man pushes again a little later with a force of 900 N, the chest moves across the floor at a steady speed.
  How big is the friction force then? Explain your answer.

17 There are four forces acting on a moving van: F_A, F_B, F_C and F_D (figure 19).
- **a** State the names of these four forces.
- **b** The sizes of forces F_A and F_B can change.
  When is F_B equal to 0 N?
- **c** How does the van move if:
  - $F_A > F_B$?
  - $F_A = F_B$?
  - $F_A < F_B$?



▶ **figure 19**
the forces on a van

d The van has an oil leak and it is losing one drop of oil every second. Figure 20 shows you the oil trail that the van has left on the road, moving from left to right.
Describe the van's motion:
- between A and B.
- between B and C.
- between C and D.



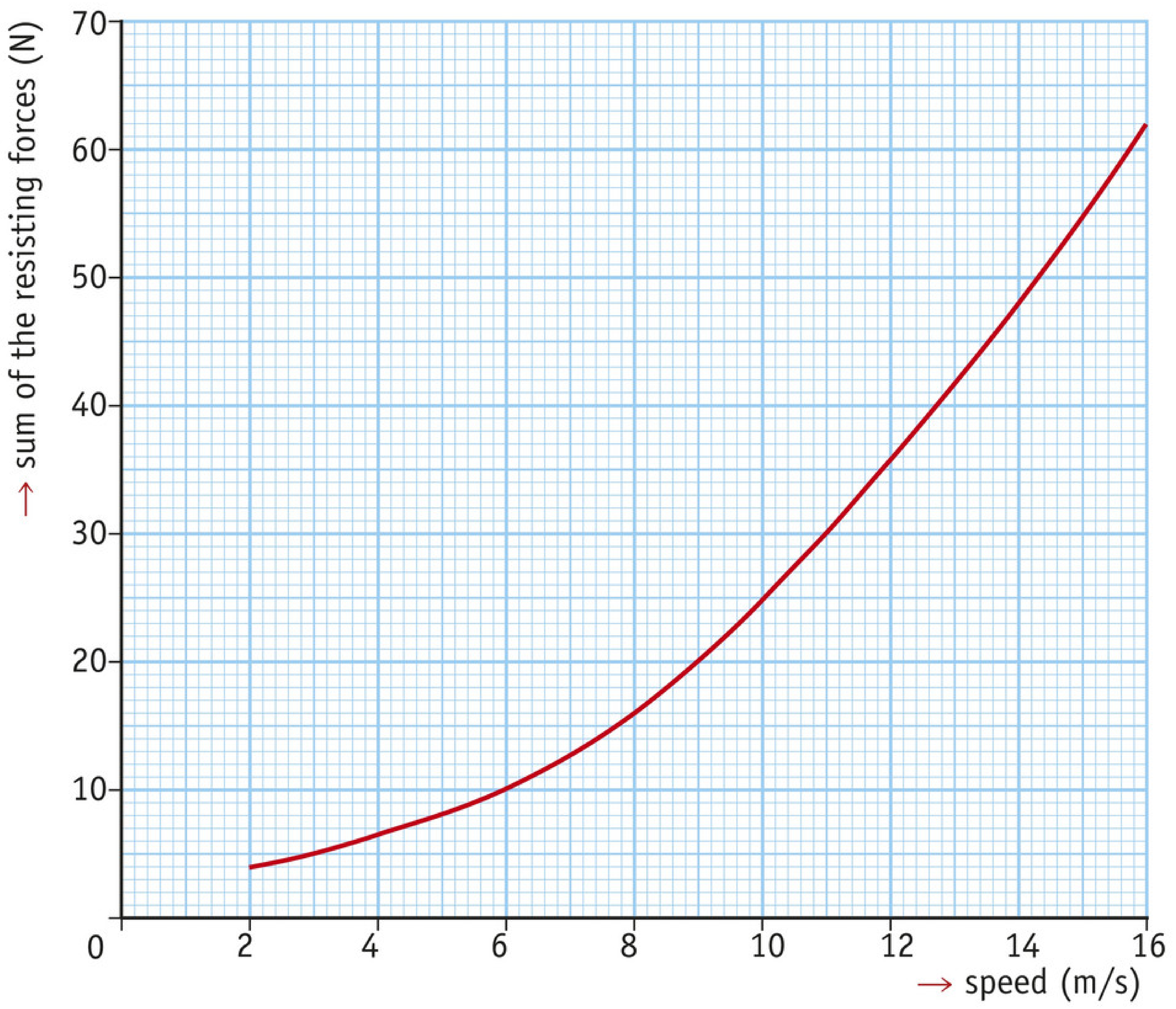
▶ **figure 20**
a trail of oil drips

18 Carla trains regularly on her racing bike. Figure 21 shows the relationship between the (overall) resisting force and the speed she is cycling at.

a Carla starts by cycling for a while at a steady speed of 11 m/s. How big is the driving force then?

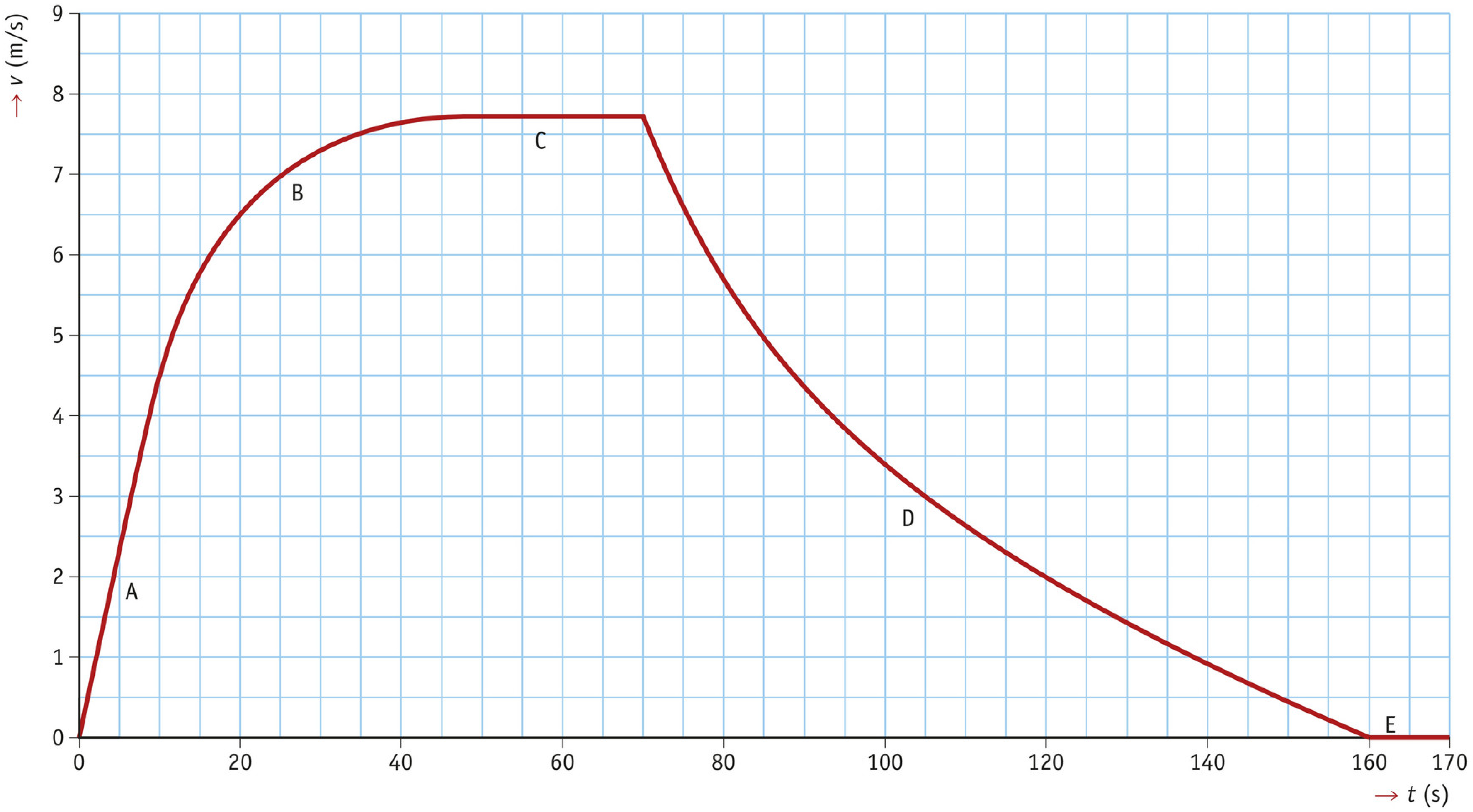
b At a certain point, Carla starts pushing harder on the pedals. This means that a (constant) driving force of 40 N is applied to her bicycle for a while.
What is the resultant at the moment when she starts to accelerate?

c Determine the final speed that Carla achieves.



▶ **figure 21**
the relationship between the speed and the resisting forces

19 Janet goes a short distance on her bike. Figure 22 gives the (v,t) diagram for her motion. The graph has been divided into five sections, A, B, C, D and E.
Is F_p greater than F_r, the same as F_r or less than F_w:
a in part A of the motion?
b in part B of the motion?
c in part C of the motion?
d in part D of the motion?
e in part E of the motion?



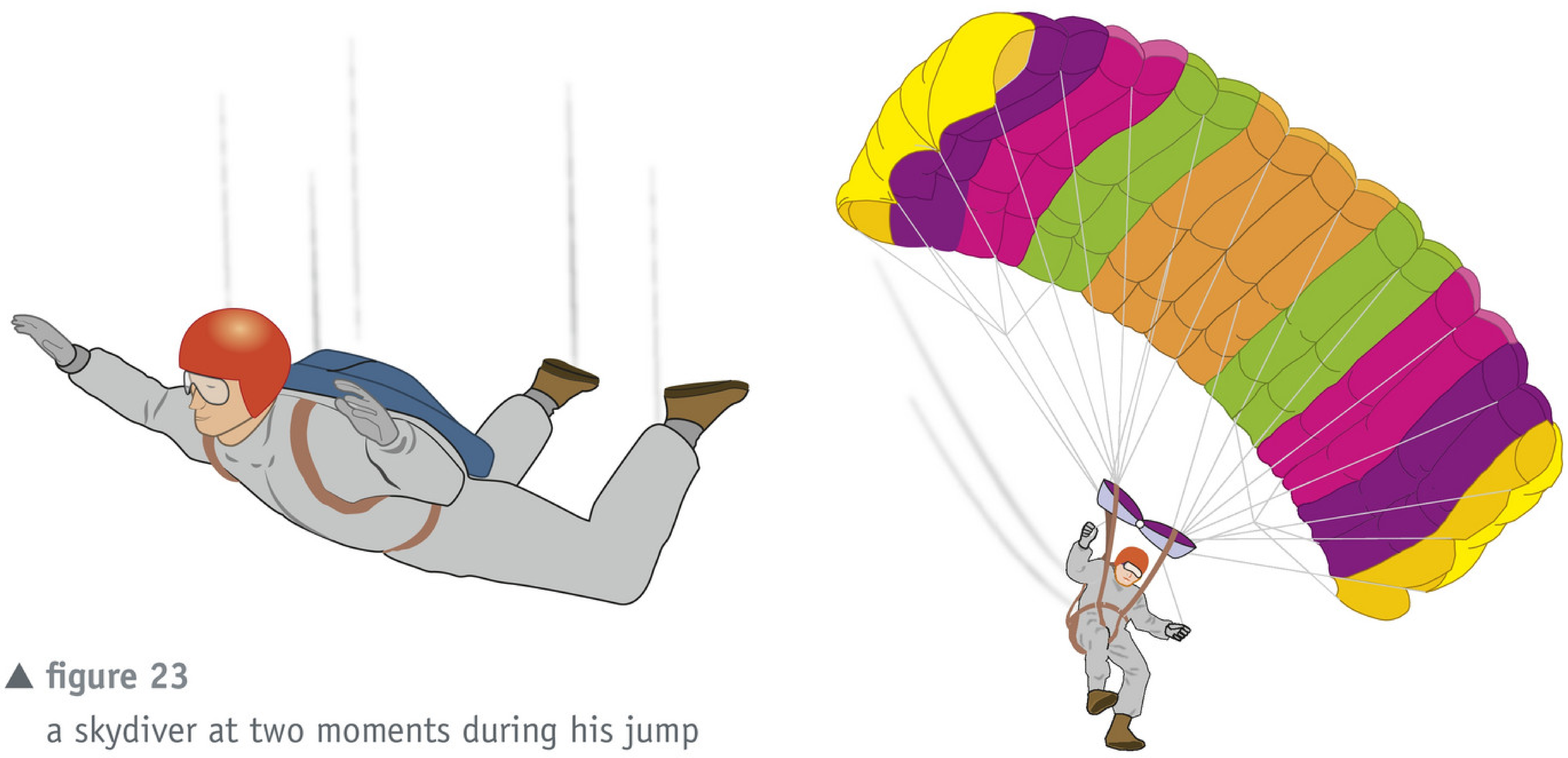
▲ **figure 22** the (v,t) diagram of Janet's motion

***20** There are two forces acting on a lift cage, gravity (F_g) and the tension in the cable (F_t). The friction forces are small enough that they may be ignored.
Compare the sizes of F_g and F_t in the following situations:
a The cage is moving up and its speed is increasing.
b The cage is moving up at a steady speed.
c The cage is moving up and its speed is decreasing.
d The cage is suspended and not moving.
e The cage is moving down and its speed is increasing.
f The cage is moving down and its speed is decreasing.

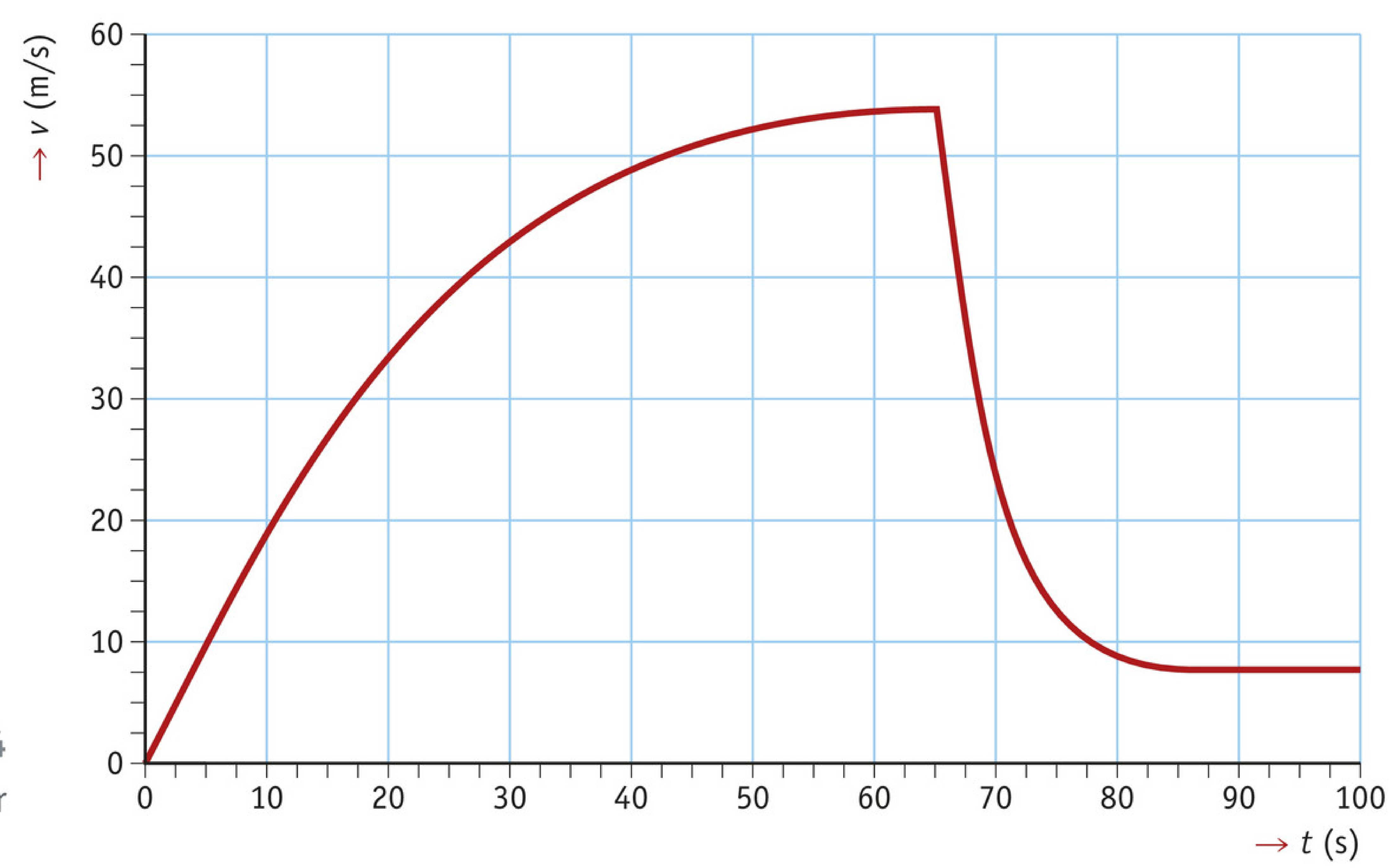
Plus Skydiving

21 A skydiver jumps out of a plane. Figure 23 shows you two snapshots of his jump. In both situations, the skydiver is falling at a constant speed. When you compare the two situations, what can you say about:
- **a** the size of the resultant?
- **b** the speed?
- **c** the amount of air resistance?

22 Figure 24 shows you how the speed of the skydiver changes during his jump.
- **a** Why does the gradient of the first part of the fall get less and less?
- **b** At what time did the skydiver open his parachute? How can you see that from the graph?
- **c** Determine the terminal velocity of the skydiver during the final part of the motion.



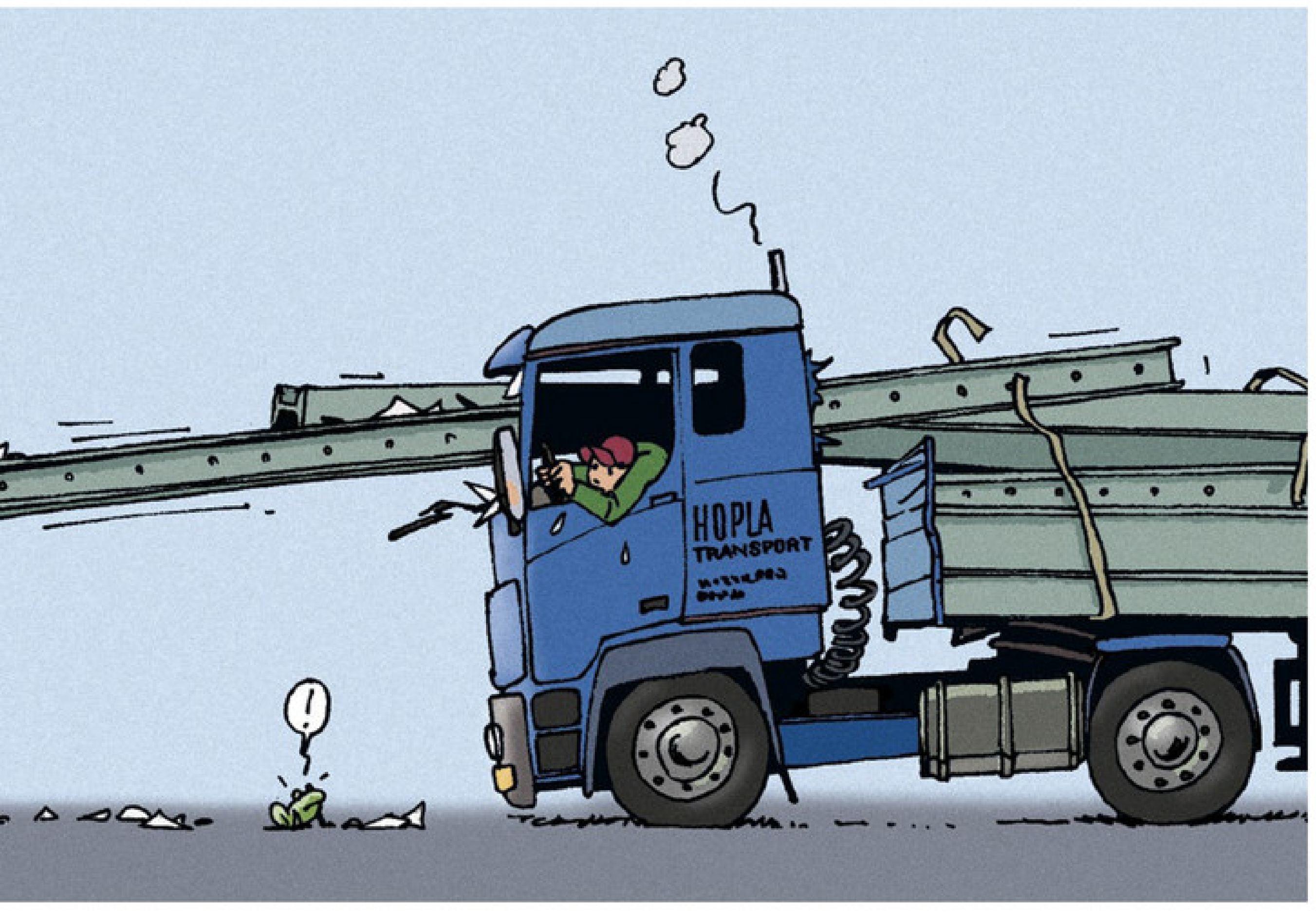
▲ **figure 23**
a skydiver at two moments during his jump



▶ **figure 24**
the (v,t) diagram of the skydiver

3 Force, mass and acceleration

When a truck is heavily loaded it can only get going slowly. The greater the mass of the load, the smaller the acceleration (if the driver is giving the same amount of gas in all cases). You will notice the same effect if you try to cycle with someone sitting on the back of your bike. Picking up speed takes much longer.



▲ figure 25
Steel girders have a large mass and therefore also a lot of inertia.

Inertia

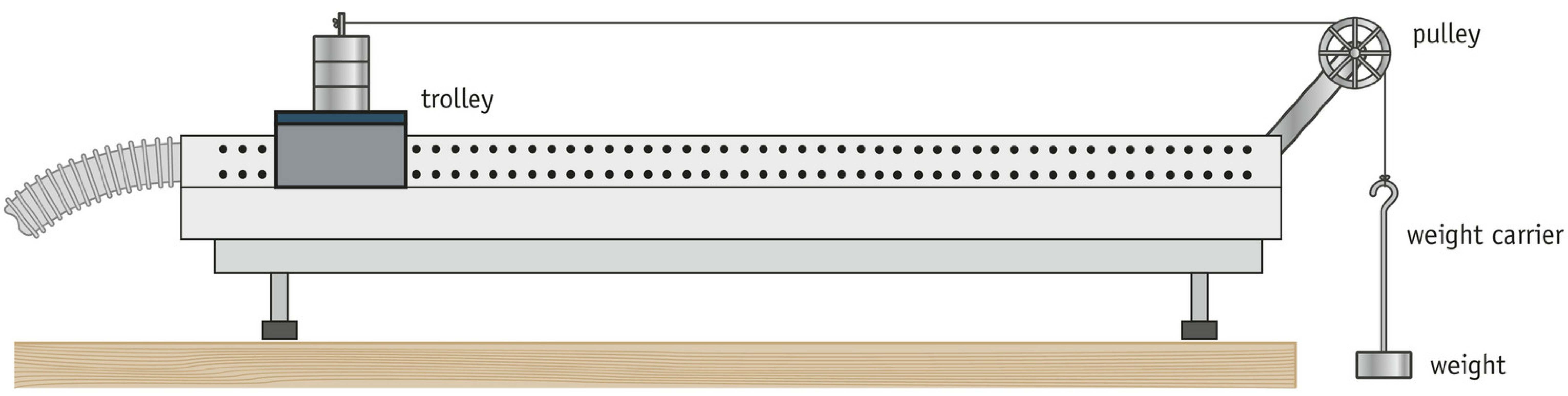
The mass does not only affect the acceleration that makes an object pick up speed, it also determines how difficult it is to brake the object or make it change direction. The greater the mass of an object, the harder it is to change the speed or the direction of motion. The driver therefore has to be extra careful if his truck is heavily loaded.

You can say that an object with a large mass has a lot of **inertia**. A large resultant is needed in order to have any noticeable effect on the speed or the direction of motion. A driver who is transporting steel girders knows that his load has a great deal of inertia. He therefore makes sure that the girders are fixed firmly in place. Otherwise they might continue moving forwards in an emergency stop, even though the truck comes to a standstill (figure 25).

Newton's Second Law Experiment 3

The setup shown in figure 26 lets you accelerate a trolley along an air-cushion track. Air flows out of the large number of small holes in the track. Because the trolley is then 'floating' on a layer of air, the forces resisting its motion are negligible. The vertical force F_v is then equal to the force of gravity on the weight carrier and the weight. The mass m of the trolley, the weight carrier and the weight can be determined using scales and the acceleration a by measuring the change in speed using a motion sensor.

▼ figure 26
an experiment with an air-cushion track



Tests like these show that there is a simple relationship between the resultant, the mass and the acceleration. Expressed as a formula:

$F = m \cdot a$

If you give the mass m in kg and the acceleration a in m/s², you get the resultant F in N. This formula is also known as Newton's Second Law.

The definition of the newton, the unit of force, is based on the formula $F = m \cdot a$. According to the definition, 1 N equals the (resultant) force that accelerates a mass of 1 kg by 1 m/s².

Worked example 4
A car accelerates in 4.0 s at a constant acceleration from 0 km/h to 54 km/h. The mass of the car is 800 kg.
Calculate the size of the resultant that is accelerating the car.

data $v_i = 0$ m/s
$v_f = 54$ km/h $= 15$ m/s
$\Delta t = 4.0$ s
$m = 800$ kg

required $F = ?$

working $\Delta v = v_f - v_i = 15$ m/s

$$a = \frac{\Delta v}{\Delta t} = \frac{15}{4.0} = 3.75 \text{ m/s}^2$$

$$F = m \cdot a = 800 \times 3.75 = 3000 \text{ N} = 3.0 \text{ kN}$$

The resultant is therefore 3.0 kN. The driving force applied to the car is greater. There are also resisting forces that have to be overcome, of course.

Calculating the acceleration

A motorbike can generally accelerate much faster than a family car. This is because the mass of the motorbike is much less. If the resultant force on both vehicles is equally large, the motorbike is therefore accelerated much more quickly. You can also work that out from the formula $F = m \cdot a$.

If the resultant F is equally large, but the mass m is much smaller, the acceleration a must be much larger.

▲ figure 27
A motorbike can accelerate much more quickly than a car.

Worked example 5
Figure 27 shows you a car and a motorbike waiting at a traffic light. The mass of the car is 900 kg and the mass of the bike is 300 kg (including the drivers). When the light turns green, the car and the bike both accelerate away. The resultant force acting on both vehicles is 1.8 kN.
Calculate the acceleration of both vehicles.

data	*car:* F = 1.8 kN m = 900 kg	*motorbike:* F = 1.8 kN m = 300 kg
required	a = ?	a = ?
working	$a = \dfrac{F}{m} = \dfrac{1800}{900} = 2.0\ \text{m/s}^2$	$a = \dfrac{F}{m} = \dfrac{1800}{300} = 6.0\ \text{m/s}^2$

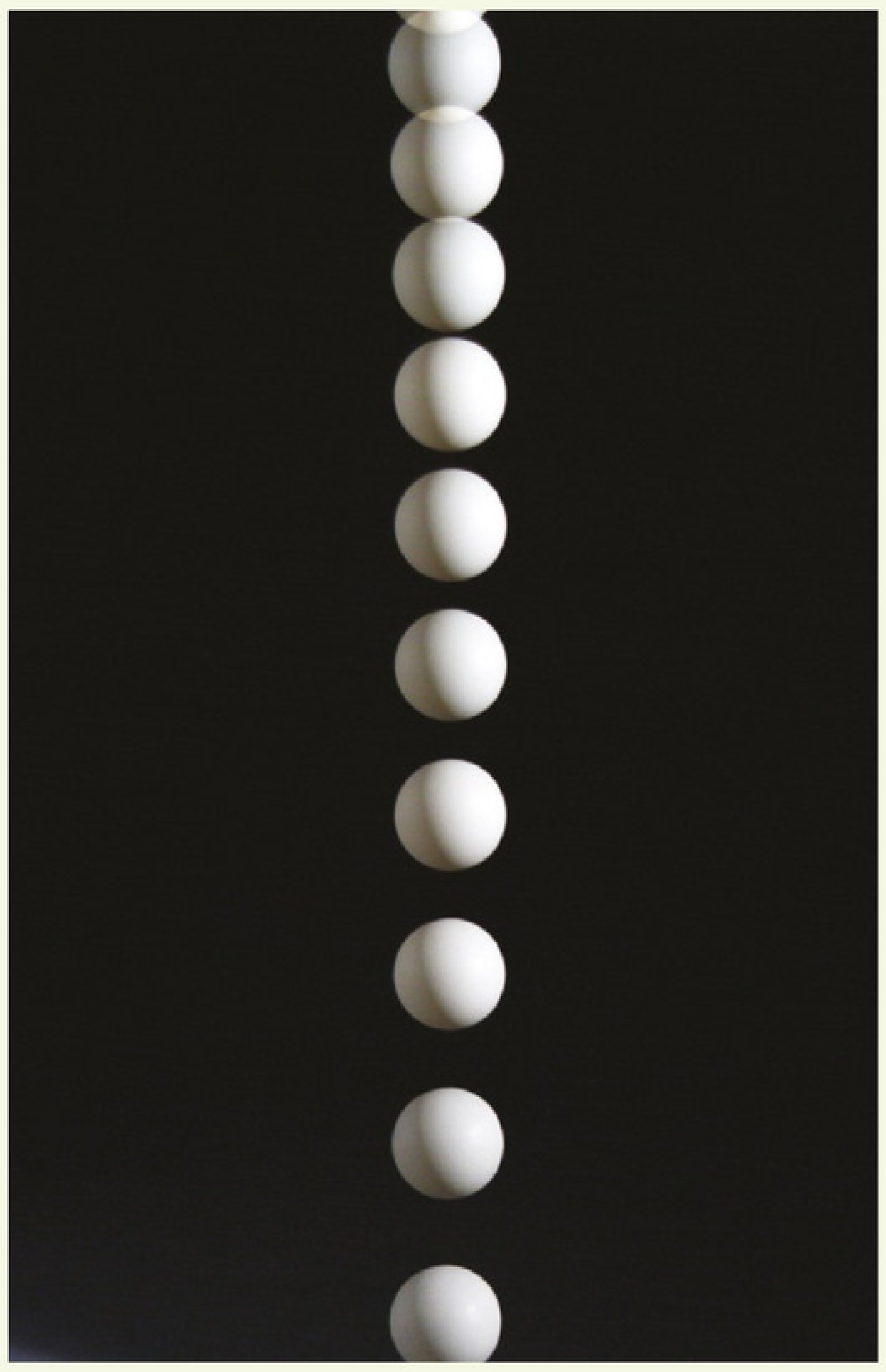
Plus Gravity and acceleration when falling

Figure 28 shows you a stroboscopic photo of an experiment with a falling ping-pong ball. The ball is accelerating downwards under the effect of gravity. If you can ignore the air resistance (compared to the force due to gravity), the following rule applies:

Near the Earth's surface, all objects fall with an acceleration due to gravity of about 9.8 m/s^2.

It makes no difference how large (or small) the mass of the object is. If the air resistance is small enough to be ignored the acceleration due to gravity is always 9.8 m/s^2. You can show that by letting things fall in a vacuum. Such tests always give the same result for the acceleration due to gravity, whether you take a lead ball or a tiny piece of cotton wool.

In daily life, however, you often cannot ignore air resistance. Think of a dandelion seed that floats down gently through the air. The seed moves with a constant speed, because the air resistance has reached the same value as the force due to gravity. This means that the resultant is 0 N. The dandelion seed only accelerated at the very start of the motion.



◀ figure 28
a ping-pong ball under a downward acceleration

Exercises

23 Answer the questions below.
- **a** What relationship do the resultant, the mass and the acceleration have?
- **b** How is it possible for the trolley on the air-cushion track to experience (almost) no resisting forces?
- **c** What is the definition of the newton (N), the modern unit of force?
- **d** Why can a motorbike generally accelerate much faster than a family car?

24 A fully loaded truck will have much more inertia than an empty one. How will the driver notice this:
- **a** when accelerating?
- **b** when cornering?
- **c** when braking?

25 Formula 1 cars are able to take bends at extremely high speeds. The drivers train their neck muscles specially for this.
- **a** Explain why this is necessary. Use the word 'inertia' in your explanation.
- **b** A Formula 1 car accelerates much more quickly than an average family car.
  Give two possible reasons for this.

26 A moped accelerates from 0 to 36 km/h is 4.0 seconds. Including the driver, the mass of the moped is 140 kg. You may assume that the acceleration is uniform.
- **a** Calculate the acceleration.
- **b** Calculate the size of the resultant that is accelerating the moped.

27 The Airbus A380-800 is the world's largest passenger aeroplane. In the run-up to take-off, the motors provide a thrust of $1.2 \cdot 10^6$ N. The mass (including fuel and load) is $5.6 \cdot 10^5$ kg.
- **a** Calculate the acceleration during the first seconds as it takes off (ignoring any friction forces).
- **b** Show that the speed of the Airbus after 3 s is 6.4 m/s (23 km/h).
- **c** Draw the (v,t) diagram of the motion of the Airbus during the first 3 s.
- **d** Determine the distance covered by the Airbus during the first 3 s.

***28** There are also cars that are powered by jet engines.
Calculate the speed in km/h that a car of mass 1200 kg would have after 3 s if it was powered by one of these engines. Ignore the air friction.

The physics of the world's fastest man

The reigning Olympic champion and world champion at the 100-metre and 200-metre sprints, Usain Bolt, has so far managed to win six Olympic gold medals and has won the various sprint events eight times at the world championships.
The key to Bolt's success is the horizontal force he is able to generate. He comes out of the starting blocks with an acceleration of nearly 10 m/s², requiring a (horizontal) force of some 817 N.
Bolt is one of the few people who can maintain that force over the entire 100 metres. Because the air resistance increases rapidly, his acceleration soon falls away after the start. Between the fourth and fifth seconds, his acceleration drops to zero and he completes the rest of the race at a constant speed of 12.2 m/s.

Source: http://www.gizmag.com/usain-bolt-fastest-man-physics-analysis/28457/

▲ **figure 29**
an Internet article about the legendary Usain Bolt

29 Read the Internet article in figure 29.
- **a** Use the data in the text to make an estimate of the mass of Usain Bolt. Tip: ignore the resisting forces at the start.
- **b** Use the data from the text to sketch the (v,t) diagram of Usain Bolt in a 100-metre sprint.
- **c** During a 100-metre sprint, Bolt covers a distance of 30 m in the first 4 s. From the fourth second onwards, he is no longer accelerating and covers the rest of the race at a constant speed of 12.2 m/s. Calculate Bolt's time in this race.

***30** Figure 30 shows you a test report for the Nissan Qashqai.
- **a** The term 'kerb weight' (in other words, ready to drive away) is incorrect in physical terms. What physical variable is it actually describing?
- **b** The test report says how quickly the Qashqai can accelerate from 0 to 100 km/h. Calculate the size of the (average) resultant acting on the Qashqai.
- **c** The driving force on the car is actually (a lot) greater than the force that you calculated for question b. Give an explanation for this.

dimensions and weights	
tank volume	55 L
kerb weight*	1250 kg
trailer	675 kg
trailer (braked)	1200 kg
performance	
gears	6
acceleration 0 to 100 km/h	11.3 s
top speed	183 km/h

(*) including the driver and a full tank of fuel
Source: www.autozine.nl

▲ **figure 30**
a test report on the Nissan Qashqai

***31** Continuation of exercise 30.
Figure 30 also states the maximum permissible mass for braked and unbraked trailers.

- **a** Explain what is meant by a 'braked trailer'.
- **b** Explain why the mass of a braked trailer is allowed to be much greater than the mass of an unbraked trailer.
- **c** Two Qashqais A and B accelerate as quickly as possible from stationary. Qashqai A is towing a trailer of 1200 kg, whereas Qashqai B is not towing anything. There are no other differences between the cars. Show that the acceleration of Qashqai B is roughly 2× greater than the acceleration of Qashqai A.

Plus Gravity and acceleration when falling

***32** During one of the Moon landings in July 1971, the American astronaut David Scott did a simple experiment with falling objects. He dropped a hammer and a feather at the same time from the same height. On a video that was made of this experiment you can see that the two objects hit the ground on the Moon at the same time.

- **a** Why did the feather reach the ground on the Moon at the same time as the hammer, rather than floating down slowly?
- **b** Measurements of the video show that the feather and the hammer both land after 1.4 s with a speed of 2.3 m/s.
  Use this data to calculate the acceleration due to gravity on the Moon.
- **c** Show that the two objects were released 1.6 m above the Moon's surface.

***33** In 1997, the Thrust Super Sonic Car (figure 31) became the first car ever to go faster than the speed of sound, 1223 km/h. At the start, this jet-engine powered vehicle reached a speed of 161 km/h in 4.0 s.
Use a calculation to find out whether the car accelerated more in those 4.0 s than a falling pebble.

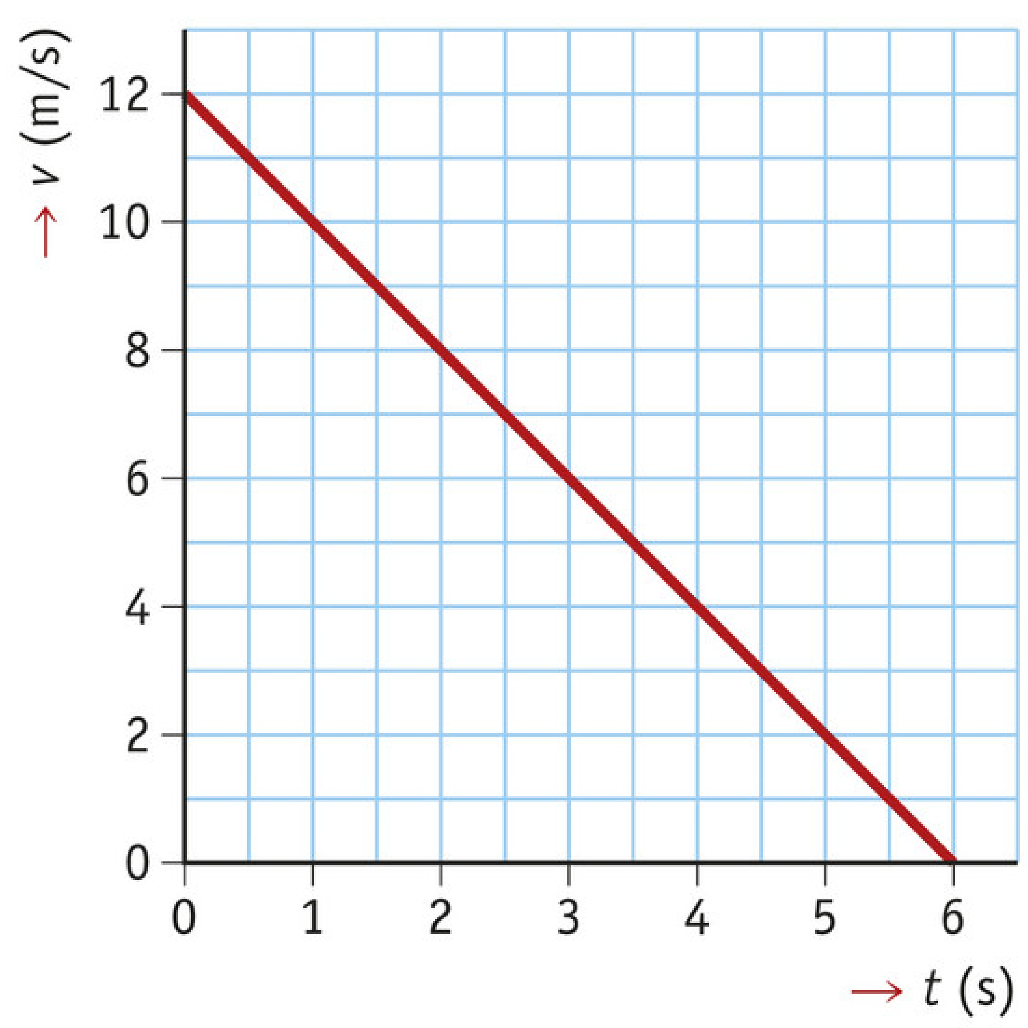
▶ **figure 31**
the Thrust SSC (= Supersonic Car) being prepared for a record attempt

4 Braking and collisions

The governmental authorities have taken all sorts of measures to make road traffic safer. For example, cars may not go faster than 50 km/h in built-up areas. There is a good reason for that. The consequences of a collision at that speed are comparable to a fall from a ten-metre building!

Uniform deceleration

Figure 32 shows the (v,t) diagram for a car that is braking for a traffic light. You can see that the speed decreases evenly until the car is stationary, the motion is a **uniform deceleration**.



▲ **figure 32**
the (v,t) diagram of a braking car

The (v,t) diagram shows you that the initial speed of the car is 12 m/s. After one second the speed is 10 m/s, after two seconds 8 m/s, after three seconds 6 m/s, and so on. In other words, the speed is decreasing by 2 m/s every second. The reduction in speed each second is called the **deceleration**. You then say that the deceleration is 2 m/s². However, you write $a = -2$ m/s².

As you can see, you use the same symbol for deceleration as for acceleration, the letter a. The only difference is that an acceleration is always a positive number and a deceleration is a negative number.

Worked example 6
A car is braking for a corner. The car decelerates uniformly for 5.0 s. During that time, the speed drops from 81 km/h to 27 km/h. Calculate the deceleration.

data $v_i = 81$ km/h $= 22.5$ m/s
$v_f = 27$ km/h $= 7.5$ m/s
$\Delta t = 5.0$ s

required $a = ?$

working $\Delta v = v_f - v_i = 7.5 - 22.5 = -15$ m/s

$$a = \frac{\Delta v}{\Delta t} = \frac{-15}{5.0} = -3.0 \text{ m/s}^2$$

Calculating the braking force

The formula $F = m \cdot a$ lets you calculate the resultant force on a braking vehicle. In this case, the letter a stands for the braking deceleration (the reduction in speed each second). The letter F stands for the resultant, as always. In this case, the resultant is the total braking force that is exerted on the vehicle.

Worked example 7

An Opel Astra has a mass of 1300 kg. The brakes must be able to provide enough braking force for a braking deceleration of at least 5.2 m/s^2.
Calculate the minimum braking force required.

data $\quad m = 1300$ kg
$\quad\quad\quad a = -5.2$ m/s^2

required $\quad F = ?$

working $\quad F = m \cdot a = 1300 \times -5.2 = -6760 \text{ N} \approx -6.8 \text{ kN}$

You say that the braking force (after rounding) is 6.8 kN, but you have to write $F \approx -6.8$ kN. The minus sign shows that the braking force is acting in the opposite direction to the direction of motion.

▲ **figure 33**
In this situation, the braking force was insufficient.

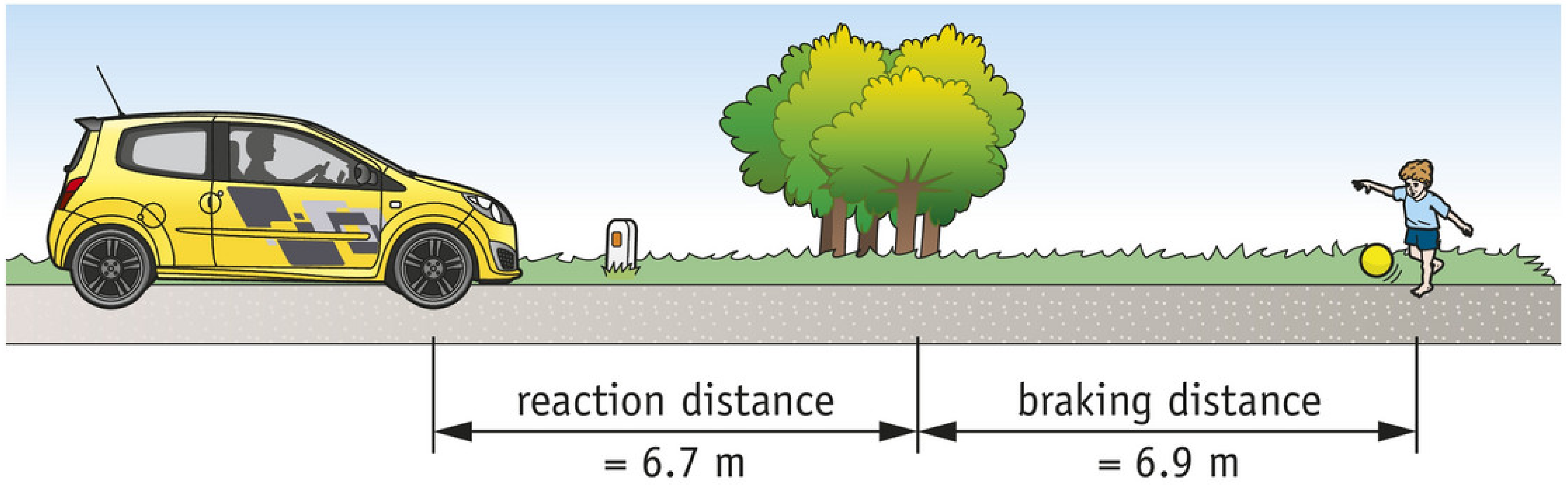
Determining the stopping distance

When car drivers see that they have to stop, the car does not start braking immediately. It takes a little time before the brake pedal is pressed and the brakes are applied. The time required for this is called the **reaction time**. During the reaction time, the car continues without braking. The distance that the car covers during this uniform motion is called the **reaction distance**.

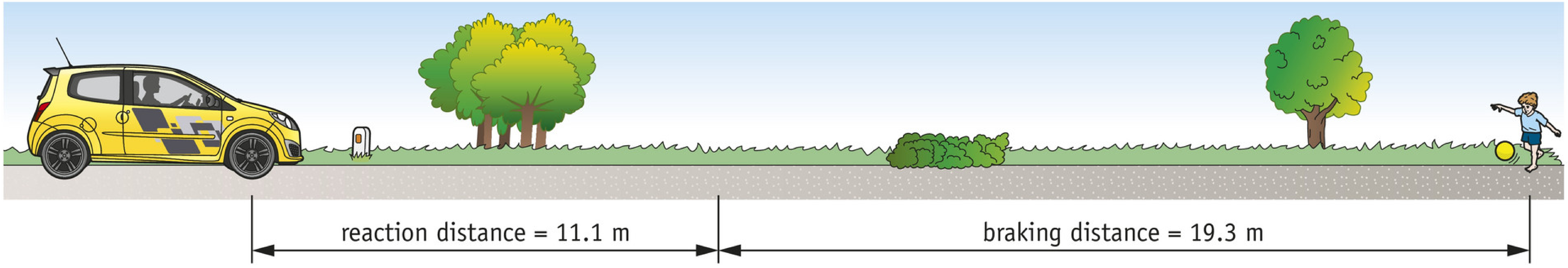
After the brake pedal has been pressed, the car decelerates uniformly until it is stationary. The distance that the car covers during this uniform deceleration is called the **braking distance**. The total stopping distance therefore consists of two parts, the reaction distance and the braking distance:

stopping distance = reaction distance + braking distance

The faster someone is driving, the greater the reaction distance and the braking distance will be, and therefore the greater the stopping distance (figure 34).

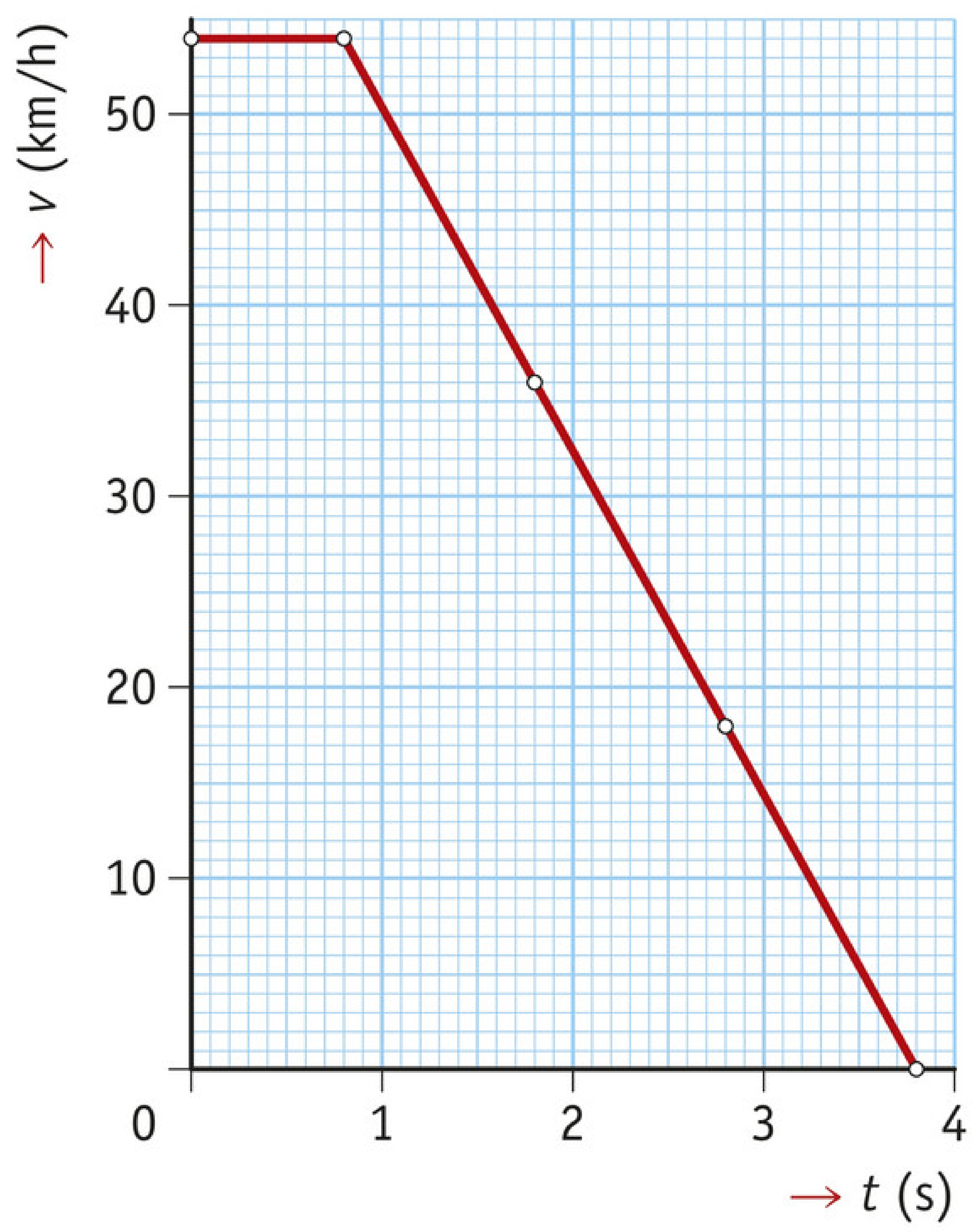


At 30 km/h, the stopping distance is 6.7 + 6.9 = 13.6 m.



At 50 km/h, the stopping distance is 11.1 + 19.3 = 30.4 m.

◀ **figure 34**
the stopping distance at a reaction time of 0.8 s and a deceleration of 5 m/s²



▲ **figure 35**
Stopping for a zebra crossing: first the reaction, then the braking.

Figure 35 is the (v,t) diagram for a car that is braking for a zebra crossing. As you can read off from the diagram, the reaction time is 0.8 s. After that, the car decelerates for 3.0 s until it is stationary. You can determine the stopping distance by calculating the area under the curve for the (v,t) diagram. If you do that for figure 35 (after you have converted the speeds from km/h to m/s), you get a stopping distance of 34.5 m. Prove for yourself that this is correct.

Collisions Experiment 4

During a collision, the people in a car are brought suddenly to a halt. That means that they undergo a high deceleration. How much that deceleration is depends on two factors:

- the speed of the car at the moment of collision;
- the time it takes to bring their body to a standstill.

The greater the (magnitude of the) deceleration a, the greater the braking force F exerted on their bodies. That comes directly from the formula $F = m \cdot a$. To reduce the risk of injuries, you must therefore keep the deceleration as small as possible. You can do that either by reducing the driving speeds or by making the collision time longer.

Worked example 8
In a crash test with a car, a crash dummy (80 kg) comes to a standstill in 0.06 s. The car's speed is 9.0 m/s. The dummy is held in place by a belt that does not stretch.
Calculate the average braking force on the dummy.

data
$m = 80$ kg
$v_i = 9.0$ m/s
$v_f = 0$ m/s
$\Delta t = 0.06$ s

required
$F = ?$

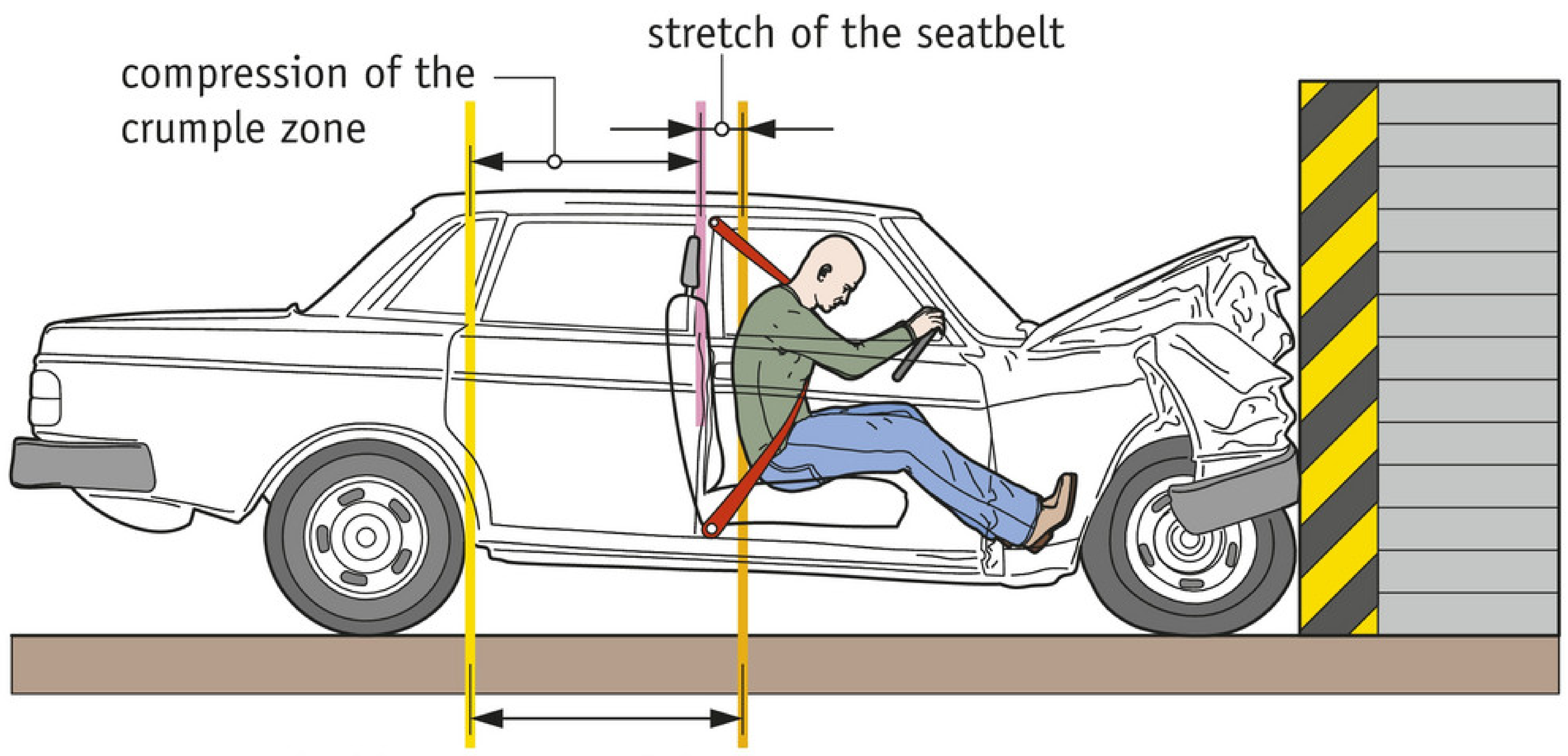
working
$\Delta v = v_f - v_i = 0 - 9.0 = -9.0$ m/s

$$a = \frac{\Delta v}{\Delta t} = \frac{-9.0}{0.06} = -150 \text{ m/s}^2$$

$F = m \cdot a = 80 \times -150 = -12{,}000 \text{ N} = -12 \text{ kN}$

Driving safely
Choosing a sensible driving speed is the responsibility of the driver. They have to asses the dangers and adjust their driving speed to suit. If there is an increased risk of a collision, for instance in very busy traffic or a slippery road surface, you should slow down. That makes it easier for you to avoid other road users, and reduces the deceleration (and therefore the force) if a collision does occur.

Extending the time that the collision takes is a task for the car designers. Over the course of time, they have thought up all kinds of ways to make the actual collision time as long as possible. For example, the front and rear of the car are designed so that they can collapse inwards easily when there is a collision. These **crumple zones** make the 'collision time' longer for the people inside the car, and the braking forces are correspondingly less (figure 36).



▶ **figure 36**
A collision test. You can see how the braking distance (and therefore the braking time) is made as long as possible for the occupants.

Seatbelts and airbags also make sure that the occupants are decelerated along with the car itself (which has a relatively long collision time) rather than all at once when they hit the windscreen (with an extremely short collision time). On top of that, the seatbelts and airbags spread the braking forces out over a larger area. This also reduces the likelihood of injuries.

Plus G forces

Accelerations are often compared to the acceleration due to gravity on the Earth (9.8 m/s^2). The acceleration due to gravity is then referred to as '1 g'. A normal family car for example has a maximum acceleration of 0.3 g (or $0.3 \times 9.8 \approx 3$ m/s^2). During launch, astronauts are subjected to an acceleration of 3 g. When a Formula 1 car makes an emergency stop, the deceleration can be as much as 6 g (figure 37). Similar accelerations and decelerations can also be achieved on roller coasters.

High accelerations and decelerations can be dangerous because they can involve large forces. The forces that are caused by these accelerations or decelerations are also referred to as g forces. The effect on the body depends not only on the size of the acceleration or deceleration, but also on the direction.

A sustained acceleration upwards makes the blood go to your legs, reducing your ability to see properly. Unconsciousness can occur at above 5 to 6 g. Sustained downward accelerations are even more harmful. In this case just 2 to 3 g can cause injury, particularly to the eyes. Forward and backward accelerations are not nearly so dangerous. People are able to tolerate up to 50 g for very short periods, for example during traffic collisions.

◀ **figure 37**
A racing driver is exposed to high g forces.

Exercises

34 Answer the questions below.
- **a** What do you call a motion where the speed is decreasingly evenly?
- **b** What does it mean if you say that 'the deceleration of the car is 5 m/s^2'?
- **c** What two distances do you have to add together to find the overall stopping distance?
- **d** What factors affect the deceleration that the body is subjected to during a collision?

35 Explain:
- **a** what happens to the crumple zone of a car during a collision.
- **b** why a crumple zone reduces the risks for the occupants.
- **c** how is it possible for a seatbelt to reduce the force of the collision on the body.

36 Three uniform decelerations are described below.
Work out what the deceleration was in each of the motions.
- **a** Caitlin is cycling at a speed of 5 m/s. She stops pedalling. After 20 s, her speed has dropped to 2.3 m/s.
- **b** A car that is going at 72 km/h stops for a traffic light. The car is at a standstill after 7 s.
- **c** A car travelling at 50 km/h hits a tree. The driver is stationary 0.3 s later.

37 Read the newspaper article in figure 38.
- **a** Explain whether the pupils in the bus fell forwards or backwards.
- **b** What safety requirement had the pupils not observed?
- **c** The bus driver (mass 95 kg) braked with a deceleration of 6 m/s^2. He was wearing a seatbelt.
  Calculate the force that the seatbelt exerted on the driver.

Bus driver punishes by braking: two children injured

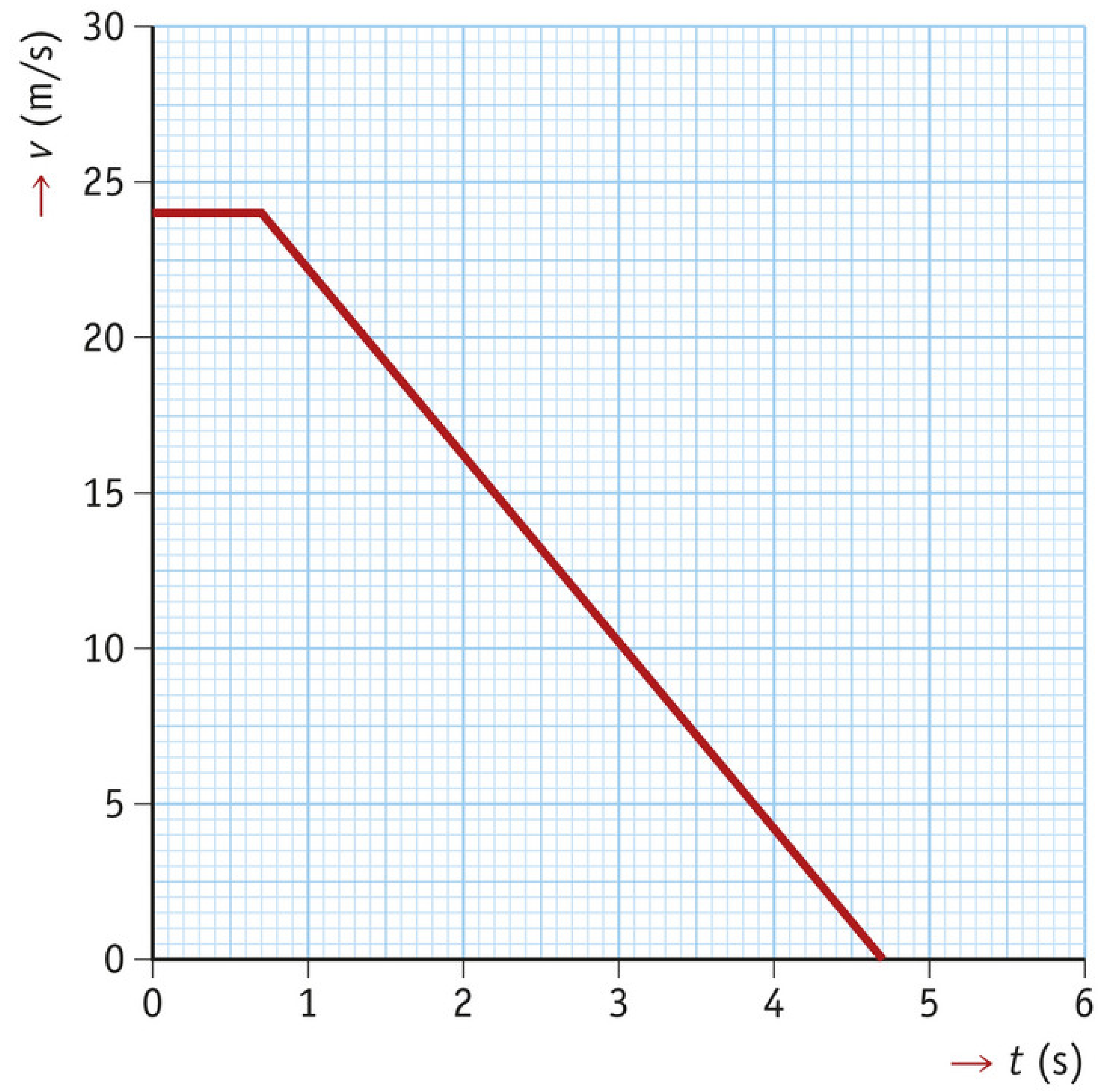
Enkhuizen – One boy and one girl were injured during a bus journey. It happened when the bus driver braked hard on the motorway in order to get the pupils to listen to him. This made the two victims fall over.
The chauffeur was very annoyed with the pupils, who were climbing over the seats. When he braked hard, the intention was to give them a bit of a fright. The boy broke an arm and the girl had to be taken to hospital with neck problems.

▶ **figure 38**
the consequences of sudden braking

38 You need worksheet 5-1 for this exercise.
Bart is driving in his car through the busy city traffic. On the worksheet, you can see the speed of Bart's car for 12 s during the journey.
- **a** Draw the (v,t) diagram of Bart's motion in the graph on the worksheet.
- **b** How can you tell that the motion between t = 3 s and t = 8 s was not a uniform deceleration?
- **c** What was the average deceleration between t = 3 s and t = 8 s?
- **d** What was the car's motion after t = 8 s?

39 A car driver sees a hare run out onto the road a short distance ahead. He tries to stop for the animal. Figure 39 shows you the (v,t) diagram of his car, from the moment (t = 0 s) that he spots the hare.

a What is the reaction time? Read it off from the figure.
b Determine the deceleration as the car brakes.
c The mass of the car plus driver is 800 kg.
Calculate the braking force that is exerted on the car.
d Use the figure to determine the stopping distance.



▶ **figure 39**
A car driver stops for a hare.

40 The airbags in a car are inflated extremely quickly if the car is subjected to a deceleration of more than 50 m/s^2. If the body of an occupant shoots forwards as the result of a collision it is cushioned by the airbag (figure 40). The airbag can be compressed inwards, just like if you press on a balloon with your finger.

a The airbag reduces the risk of the people in the car being injured in a collision.
Say how physics explains this.
b In a crash test, a car hits a concrete wall at a speed of 20 km/h. The car is brought to a halt in less than 0.10 s. The crumple zone of the car is made so that the car's deceleration is uniform during the collision. Do a calculation to see whether the airbag will be inflated in this collision or not.
c Show that the crumple zone of the car will be shortened by 28 cm in this crash test. Tip: first draw the (v,t) diagram of the motion.

◀ **figure 40**
An airbag being tested in a crash test.

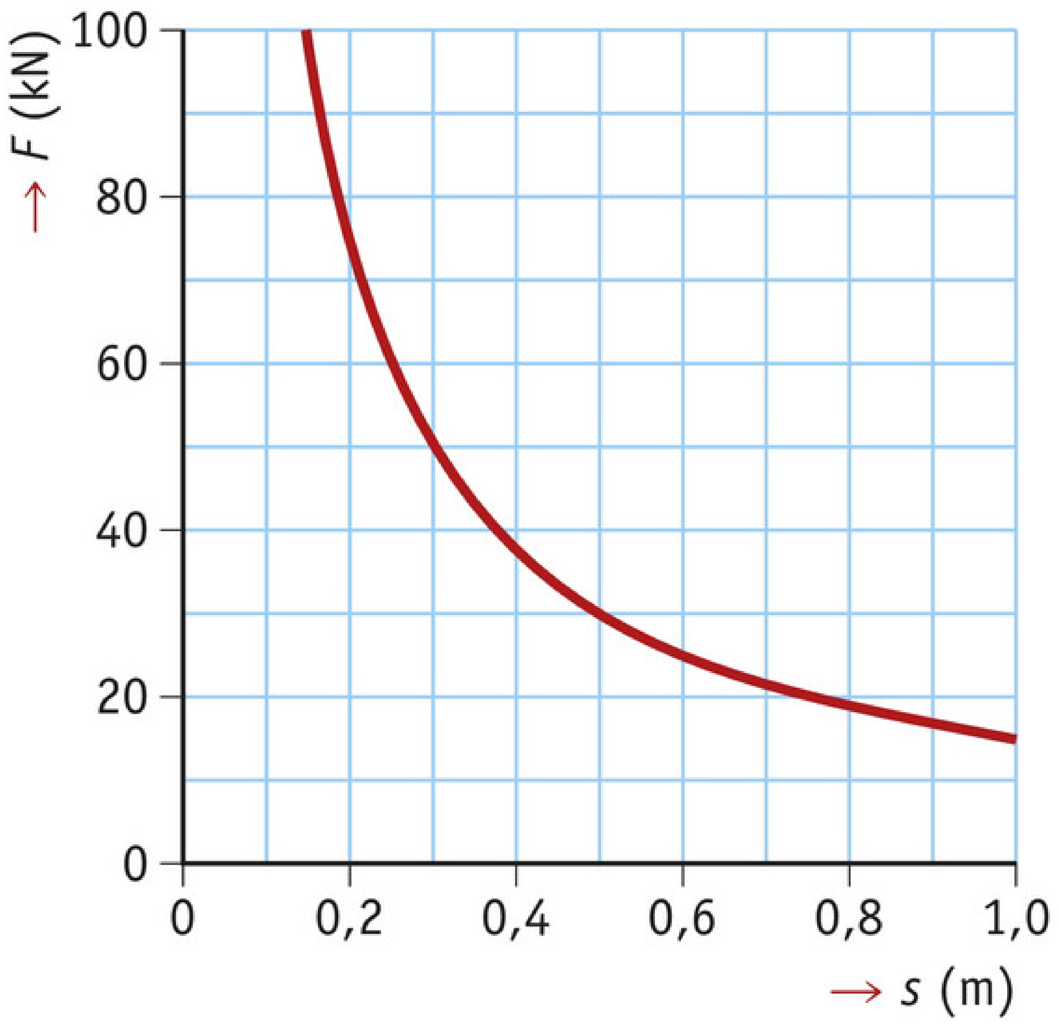
▲ **figure 41**
riding a Segway

***41** The Segway is an electrically powered two-wheeled vehicle (figure 41). Tests have shown that the stopping distance at a speed of 20 km/h is between 4.6 and 6.5 m.

a Give a reason – think one up for yourself – why the stopping distances can be so variable.

b The braking deceleration of a Segway is at least 4.0 m/s^2. A driver makes an emergency stop from 20 km/h, the Segway's maximum speed.
Calculate the maximum braking time.

c In the manual for the Segway, it recommends wearing a helmet. The helmets have a hard outer shell and an inside made of soft, springy material.
Use your knowledge of physics to explain why wearing a helmet like this reduces the risk of serious injury.



▲ **figure 42**
the relationship between the braking distance in a collision and the force on the crash dummy

***42** During a crash test, a car driving at 72 km/h hits a concrete wall. There is a crash test dummy of 75 kg in the car, wearing a seatbelt just as a normal occupant would. Figure 42 shows you how the force that decelerates the dummy varies depending on the distance that the dummy travels during the collision.

a The dummy covers a distance of 0.60 m during the collision.
Determine the (average) braking force on the dummy.

b Calculate the (average) braking deceleration.

c The distance (0.60 m) that the dummy travels during the collision is in part due to the crumple zone (50 cm) and in part due to the seatbelt stretching (10 cm).
Determine what the force on the dummy would have been if the seatbelt did not stretch.

Plus G forces

43 In downward accelerations, 2 to 3 g can be enough to cause harm.

a What is an acceleration of 2 to 3 g, expressed in m/s^2?

b Why are people less able to tolerate downward accelerations than upward accelerations? Tip: think what happens to your blood in this instance.

c Jet fighter pilots wear pressure suits that squeeze the blood vessels to the legs at high accelerations so that they close.
What can you say about the direction of these accelerations? Explain your answer.

44 A funfair attraction accelerates the people in it by 3 g at the start. Calculate how long it takes before their speed has reached 110 km/h.

Experiments

Experiment 1 Determining the acceleration 30 min

Introduction
The trolley on an air-cushion track floats just above the rail on a thin layer of air. As a result, there is (almost) no resistance due to friction. If you put the track at a slight slope, the trolley will slide down the track under a steady acceleration.

Aim
In this experiment, you will be determining the acceleration of the trolley on an air-cushion track.

Requirements
- air-cushion track
- trolley
- stopwatch
- ruler

Doing the experiment and writing it up
– Build the experiment as shown in figure 43. Mark the starting point and the end point of the motion.
– Measure the distance between the starting point and the end point.

1 Copy table 2 into your exercise book. Write down the distances measured in the correct place in the table.

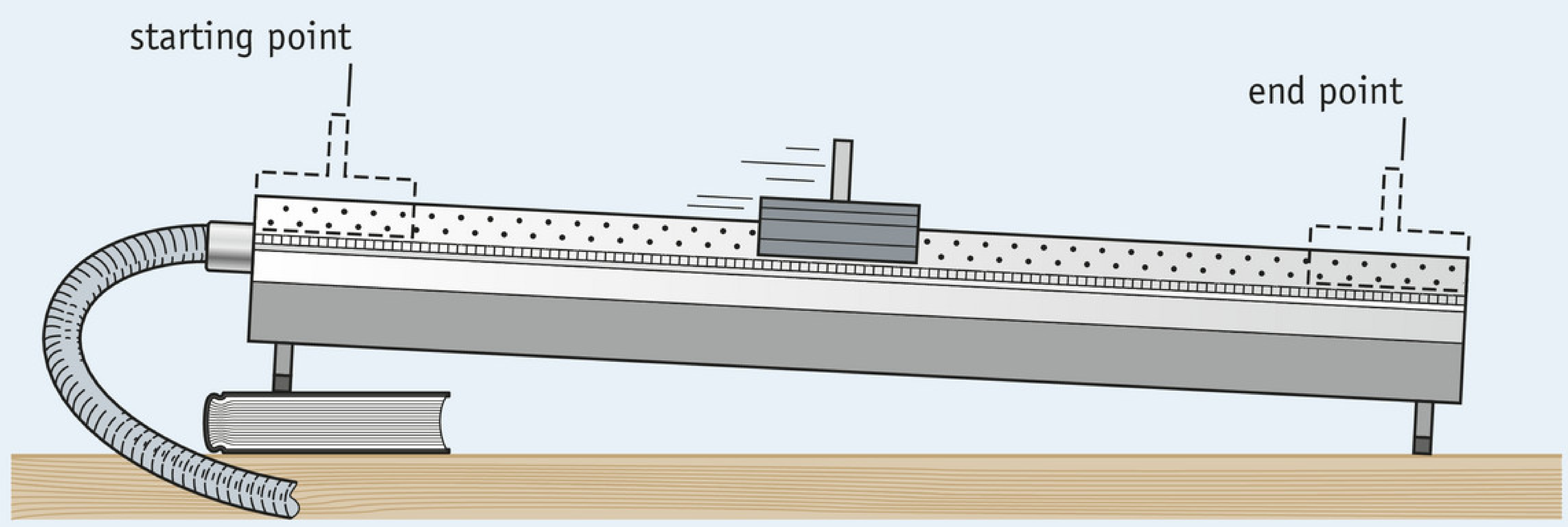
– Put the trolley at the starting position.
– Release the trolley and start timing it at that moment.
– Stop the timer when the trolley goes past the end marker.
– Carry out this measurement four times.

2 Calculate the average time. Make a note of it in the table.
3 Calculate the trolley's average speed (v_{avg}). Make a note of it in the table.
4 The final speed of the trolley is 2× the average speed.
Calculate the final speed (v_f) of the trolley. Write down that value in the table.
5 Now calculate the acceleration of the trolley. Write down the result in the table.

– Your teacher will tell you whether or not you have to write up a report on this experiment.

▼ **table 2** the results for experiment 1

distance (m)	average time (s)	average speed (m/s)	final speed (m/s)	acceleration (m/s^2)
and so forth				



▶ **figure 43**
the setup for experiment 1

Experiment 2 Air resistance and speed 45 min

Introduction
Just like a falling object, a cyclist is also affected by the resistance due to air friction. The air resistance depends on various factors. One of those factors is the object's speed.

Aim
In this experiment, you are going to investigate how the air resistance varies with the speed of an object.

Requirements
- large balloons
- paper clips
- stopwatch
- measuring tape
- accurate scales
- sticky tape

Doing the experiment and writing it up
You will be doing this experiment in pairs. Pupil 1 lets the balloon drop (from high up) and pupil 2 measures the time. You should swap roles regularly during the experiment. You can carry out the experiment in the hall or a stairwell if your physics classroom is not high enough.

- Use a piece of sticky tape to mark a spot on the wall, at least two metres above the floor. That is the height at which the timing will be started.
- Measure the distance from the marker to the ground (the fall distance).

1 Make a note of that distance in your exercise book.

- Let the balloon drop from quite some height above the mark. The idea is that the balloon should be moving at a constant speed between the mark and the ground.
- Measure the time it takes to fall.
- Repeat this measurement three times.

2 Copy table 3 into your exercise book. Write down the average fall time in the correct place in the table.

- Then attach first one paperclip to the balloon, and then two, three, four and so forth.
- Determine the (average) fall time for each number of paperclips.

3 Write down the measurement results in the correct place in the table.
4 Calculate the corresponding fall speed for each of the fall times in the table. Write down the results in the correct place in the table.

- Measure the mass of the balloon and of a paper clip.

5 For each fall time, calculate the corresponding force due to gravity on the (weighted) balloon in mN. Make a note of the results at the correct place in the table.
6 You can assume that the friction force acting on the balloon is equal to the force due to gravity (the fourth column in the table).
Explain why.
7 Draw a graph of the air resistance on the balloon against its speed.
What conclusion can you reach?

- Your teacher will tell you whether or not you have to write up a report on this experiment.

▼ **table 3** the results of experiment 2

number of paper clips	fall time (s)	fall speed (m/s)	force due to gravity (mN)
0			
1			
2			
and so forth			

Experiment 3 Acceleration and force 30 min

Introduction
The trolley on an air-cushion track floats just above the rail on a cushion of air. As a result, the friction forces are negligible. You do not have to take account of any friction forces that resist the motion, the resultant force is the same size as the driving force.

Aim
You are going to investigate the relationship between the resultant force on the trolley and its acceleration.

Requirements
- air-cushion track
- trolley
- weight carrier
- weights
- pulley
- string (2.5 m)
- stopwatch or light gate with an electronic timer

Doing the experiment and writing it up
– Build the experiment as shown in figure 44.

Measurement 1

– Your teacher will tell you how many weights to place on the trolley and on the weight carrier.

1 Copy table 4 into your exercise book. Write down the mass of the weight carrier at the correct place in the table.

– Place the trolley 2.0 m from the end point. This is the starting position.
– Measure how long it takes the trolley to reach the end of the air-cushion track.
– Repeat this measurement two more times.

2 Determine the average time. Make a note of it at the correct place in the table (next to measurement 1).

Measurement 2

– Move one weight from the trolley across to the weight carrier. The total mass (the carrier plus the trolley plus all the weights) does not change, but the driving force does.

3 Write down the mass of the weight carrier at the correct place in the table.

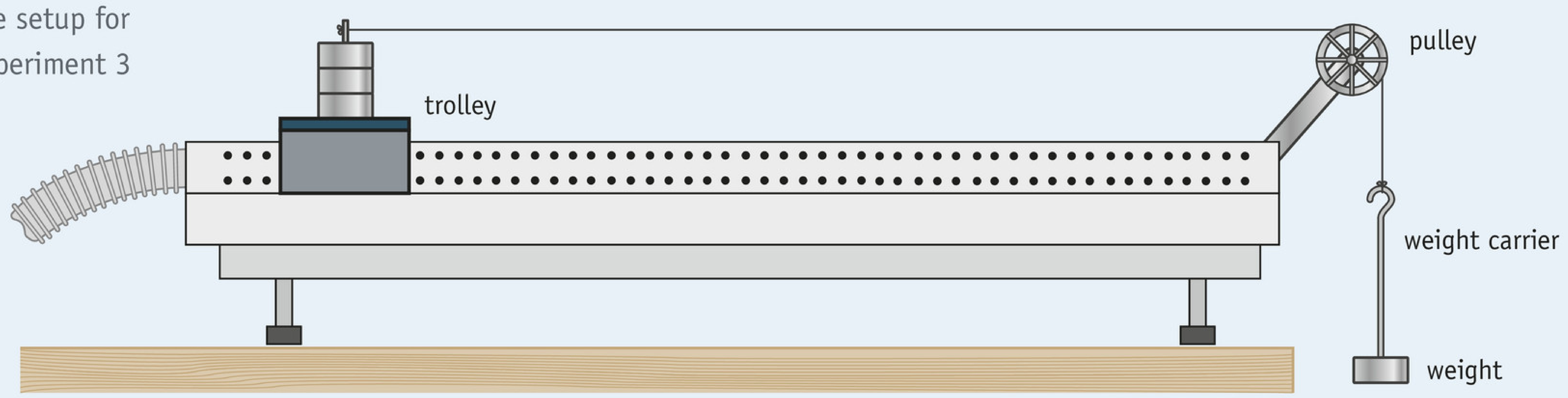
– Measure how long it takes the trolley to move from the starting point to the end of the air-cushion track.
– Repeat this measurement two more times.

4 Determine the average time. Make a note of it at the correct place in the table (next to measurement 2).

Measurement 3

– Move another weight from the trolley across to the weight carrier.

▼ **figure 44** the setup for experiment 3



▼ **table 4** the results of experiment 3

measurement	mass of the carrier (g)	force (N)	distance (m)	average time (s)	average speed (m/s)	final speed (m/s)	acceleration (m/s²)
1			2.0				
2			2.0				
3			2.0				

5 Write down the mass of the weight carrier at the correct place in the table.

– Measure how long it now takes the trolley to move from the starting point to the end of the air-cushion track.
– Repeat this measurement two more times.

6 Determine the average time. Make a note of it at the correct place in the table (next to measurement 3).

Writing up

7 Calculate the driving force for each measurement using $F_z = m \cdot g$. Write down the results in the third column of the table.

8 Calculate the average speed for each measurement. Write down the results in the sixth column of the table.

9 The final speed is 2× the average speed. Calculate the final speed for each measurement. Write down the results in the seventh column of the table.

10 Calculate the acceleration for each measurement. Write down the results in the eighth column of the table.

11 Study your results. What can you say about the relationship between the resultant and the acceleration? Explain how you got your answer.

– Your teacher will tell you whether or not you have to write up a report on this experiment.

Experiment 4 Deceleration in crash tests 20 min

Introduction

Crash tests are done in car factories in which a car is driven at high speed into a concrete wall. Videos are made of these crash tests. They let you see exactly what happens during the crash.

Aim

In this experiment, you are going to use the computer to make measurements of one of these crash tests. The question you are studying is:
What is the average deceleration during the crash?

Requirements

- video of a crash test
- video software
- computer

Doing the experiment and writing it up

To carry out this experiment, you need video software that can play a clip one frame at a time (a good program for this is VideoLAN, repeatedly pressing the 'E' key lets you play the clip frame by frame).

– Search the Internet for a clip of a crash test with a known starting speed.
– Download the clip.
– Find out the number of pictures per second (the frame rate) of the clip. You may need to look at the manual of the video software, or you can ask your teacher.

1 Make a note of the initial speed of the car and the frame rate.

– Play the clip, frame by frame. Count the number of frames in the actual collision, from the first contact with the obstacle to the moment that the car has come to a standstill.

2 Write down the number of frames taken to record the collision.

Writing up

3 Use the answers from questions 1 and 2 to calculate the duration of the collision for the car.

4 Calculate the (average) deceleration of the car during the collision.

5 What would the resultant force be on a driver weighing 80 kg if they were brought to a standstill with the same deceleration?

6 This method of determining the deceleration in crash tests is fairly inaccurate for crash tests at high speeds.
Explain why.

Experiment 5 Carrying out research – the rolling friction of a bicycle 45 min

Introduction
Suppose that a sports scientist writing in a magazine for amateur racing cyclists states, "Many amateur racers do not realise how important the correct tyre pressure is. If the tyres are pumped up hard, you are simply quicker. A couple of bar higher and the rolling resistance can be reduced by as much as 20%. In a time trial in a cycle race, the difference that can make could be several tens of seconds."
You wonder whether the scientist is right and decide to do an experiment.

Aim
You are going to look for an answer to the following study question:
How does the rolling resistance of your bicycle vary with the pressure in the bike tyres?

Requirements
For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up
- Think how you can give the most reliable answer to the question. What is your test setup going to look like; what exactly are you going to measure; how will you make sure that the measurements are repeatable (and can therefore be verified)? Tip: first think about how you can make the effect of air resistance on your measurements as small as possible.
- Talk it through together to discuss any risks that might be involved. What can you do to make sure that this experiment can be carried out safely?

1 Make a work plan for this study.

- The work plans will be discussed with the rest of the class at the next lesson. If necessary, you can make improvements to your own work plan after that.
- Then carry out the experiment.

2 Write down all the measurements, calculations and results in your exercise book.
3 Draw a graph of the rolling resistance of the bicycle against the pressure in the bike tyres.
4 Write down your conclusions.

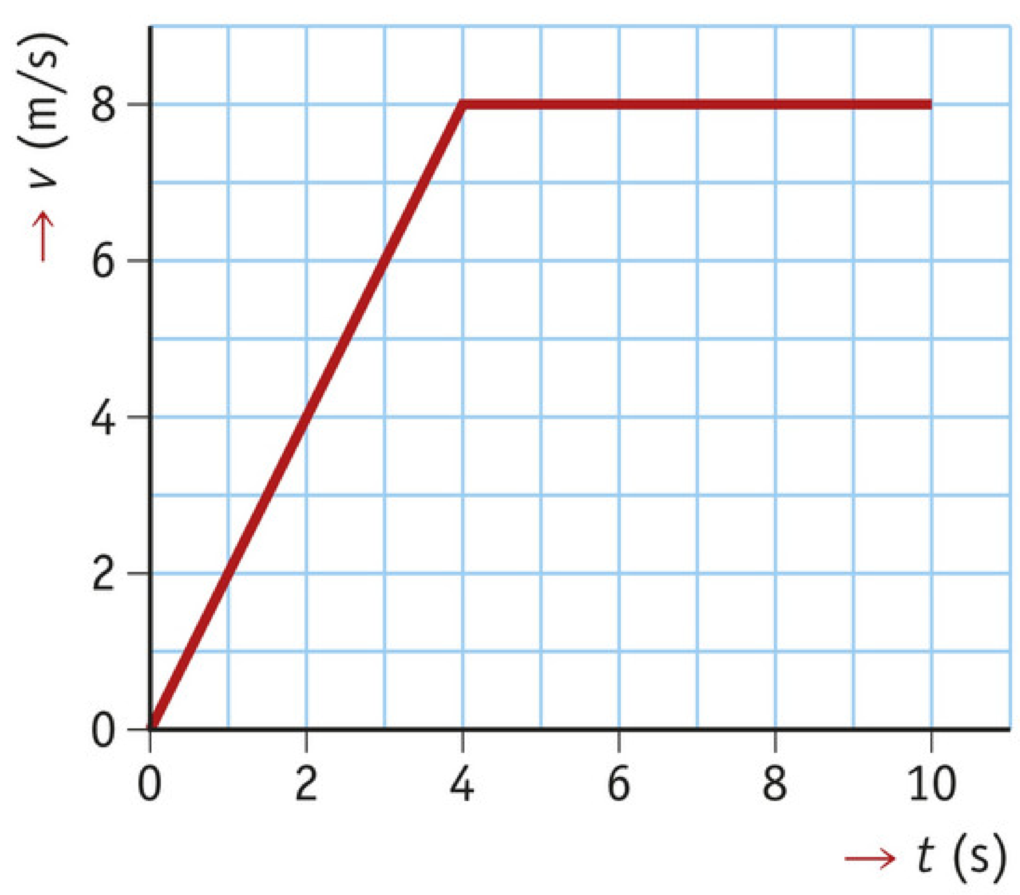
- Your teacher will tell you whether or not you have to write up a report on this experiment.

Test Yourself

You can also do questions 1 to 16 on the computer.

1 A train accelerates in 2.8 s from 72 to 99 km/h. Calculate the acceleration.

2 Figure 45 gives the (v,t) diagram for Hassan on his bicycle.
State whether each of the following statements is true or false.
- **a** Between $t = 0$ s and $t = 2$ s, Hassan covers a distance of 4 m.
- **b** Between $t = 0$ s and $t = 4$ s, Hassan's motion is a uniform acceleration.
- **c** Between $t = 4$ s and $t = 10$ s, the acceleration is constant: 8 m/s^2.
- **d** After time $t = 4$ s, the distance covered does not increase any more.

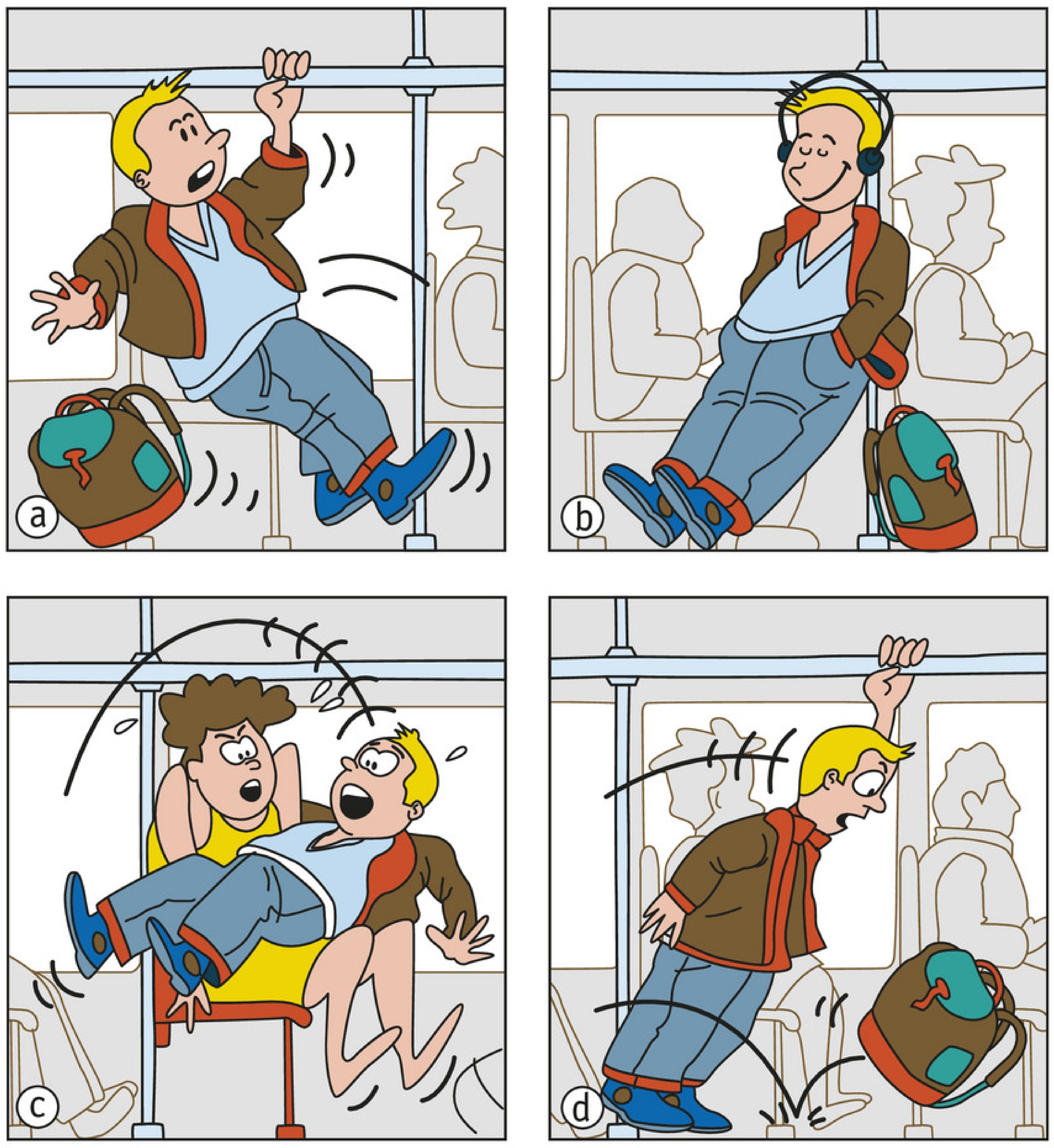


▲ **figure 45**
Hassan's motion

3 Continuation of question 2.
What is the distance that Hassan covers in 10 s?
A 2 m
B 8 m
C 40 m
D 64 m
E 80 m

4 A motorbike rider accelerates from a standing start. The bike accelerates uniformly for 2.5 s at an acceleration of 6.2 m/s^2.
Calculate how fast the motorbike is going after those 2.5 s (in km/h).

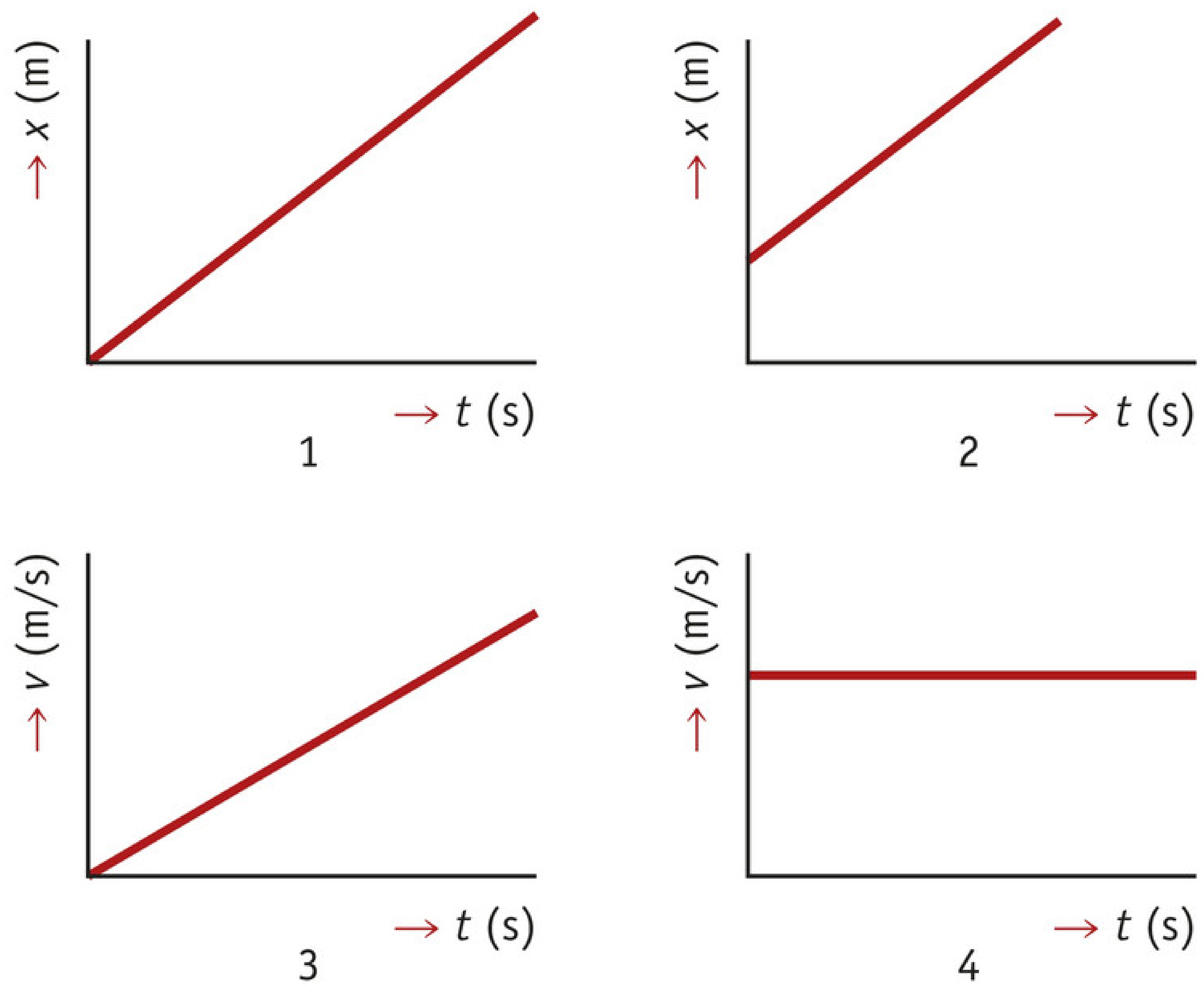
5 The bus was crowded and Hughie was unable to find a seat. So he is now standing in the aisle (figure 46).
In which picture:
- **a** is the bus making a sharp turn to the right?
- **b** is the bus driving at a constant speed?
- **c** does the bus start off suddenly?
- **d** does the bus brake suddenly?



▲ **figure 46**
Hughie's journey

6 A car accelerates from 90 to 120 km/h.
Ahmed says, "While it is accelerating, the driving force is greater than all the resisting forces together."
Stella says, "As it accelerates, the air resistance experienced by the car keeps getting greater."
Who is right?
A Ahmed and Stella are both right.
B Ahmed is right but Stella is wrong.
C Stella is right but Ahmed is wrong.
D Ahmed and Stella are both wrong.

7 Figure 47 shows two (x,t) diagrams and two (v,t) diagrams for a cyclist.
Which diagram (or diagrams) represents a motion in which the resultant on the cyclist is 0 N?



▲ **figure 47**
In which motion was the resultant 0 N?

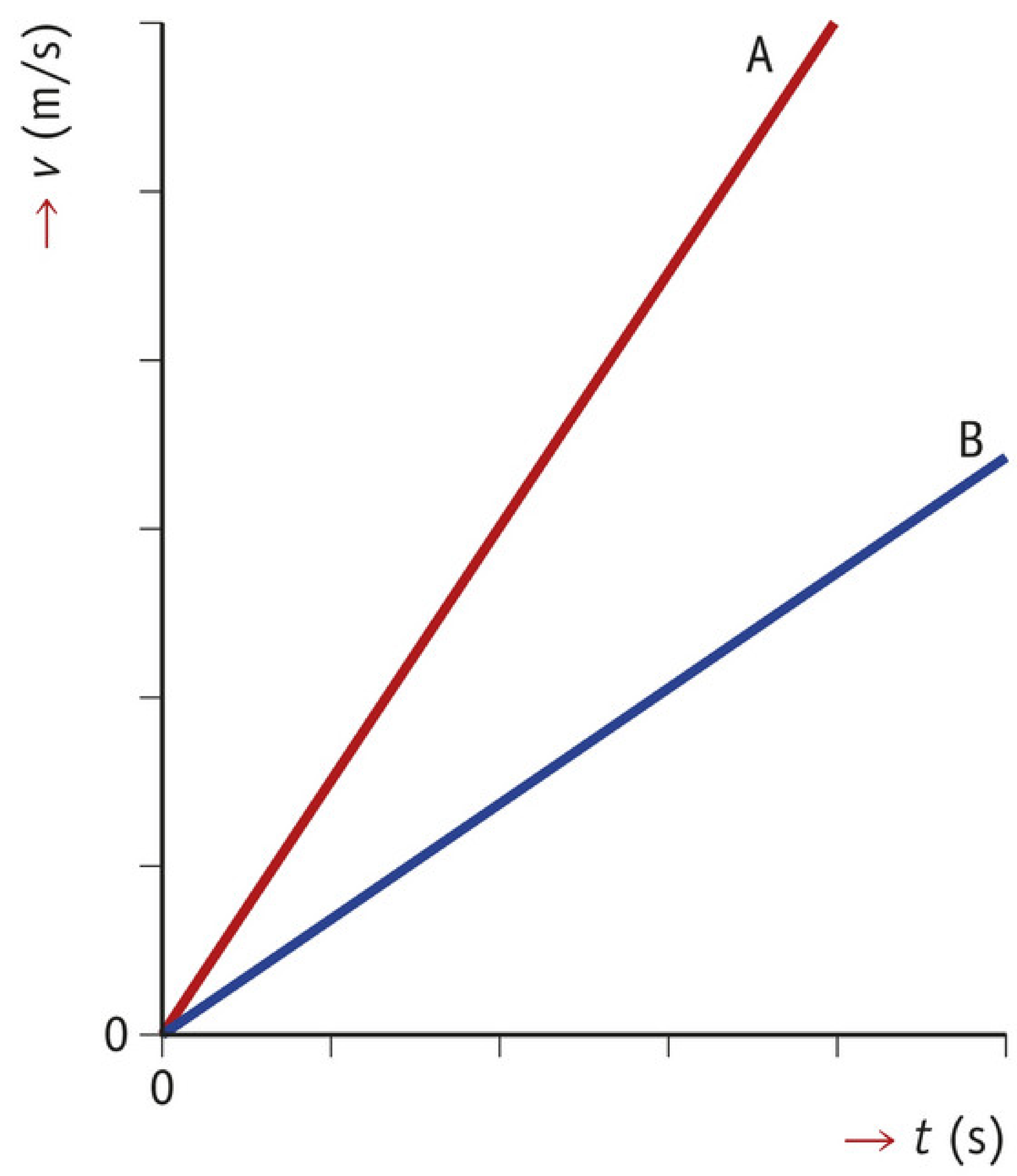
8 State whether each of the following statements is true or false.

- **a** There are always forces resisting the motion of a moving car, such as the air resistance and the rolling friction.
- **b** Family cars generally have streamlined shapes because the rolling resistance is then much less.
- **c** While a car driver presses the clutch pedal, the car will continue at a constant speed.
- **d** If the resultant force is perpendicular to the direction of motion of a car, the car's speed will not change.

9 A resultant force of 1 N is acting on an object weighing 1 g.
Under the influence of that resultant, the object moves:

A at a speed of 1 m/s.
B at a speed of $1 \cdot 10^3$ m/s.
C with an acceleration of 1 m/s^2.
D with an acceleration of $1 \cdot 10^3$ m/s^2.

10 Figure 48 shows you the (v,t) diagrams of two accelerating cars (A and B). As they picked up speed, the resultant forces acting on both vehicles were the same.
Which car had the greater mass?



▲ **figure 48**
Which car has the greater mass?

11 During the launch of a rocket, the acceleration at a given moment is 20 m/s^2. The mass of the rocket is $3.0 \cdot 10^6$ kg.
Calculate the size of the resultant thrust acting on the rocket.

12 Continuation of exercise 11.
During the launch, the rocket motor provides a constant thrust for a period of time. However, the mass of the rocket decreases during that time because fuel is being consumed.
What will therefore happen to the rocket's acceleration?

A The acceleration will get less and less.
B Nothing, the acceleration remains constant.
C The acceleration will keep increasing.

13 A car driver brakes for a sharp bend. The braking force that then acts on the car, which has a mass of 1200 kg (including the driver), is 3.5 kN.
Calculate the deceleration.

14 A car that is driving at a speed of 72 km/h brakes to a standstill in 5.0 s.
What is the braking distance of the car?

A 50 m	D 150 m
B 75 m	E 180 m
C 120 m	F 360 m

15 With dipped headlights, a driver can see 70 m ahead in the dark. With infrared night vision (figure 49) on a display, you can see 140 m ahead. The infrared night vision:

A lets you see things earlier, while they are still further away.
B provides no information that makes car driving safer.
C reduces the distance that you cover during the reaction time.
D reduces the distance that you cover during braking.

▲ **figure 49**
infrared night vision

16 In a series of braking tests, the car is always going at 72 km/h before the braking starts. In addition to the speed, what else do the researchers need to know if they are able to calculate the braking force? Choose between:

a the mass of the car — *yes / no*
b the reaction time — *yes / no*
c the braking time — *yes / no*
d the driving force — *yes / no*

17 A jet fighter lands on the deck of an aircraft carrier at a speed of 243 km/h. The plane comes to a standstill in 4.5 s. The mass of the jet fighter is $12 \cdot 10^3$ kg.
Calculate the (average) force braking the jet fighter.

18 Continuation of exercise 17.

a Determine the distance covered by the jet fighter during braking.
b Calculate the average speed of the jet fighter. What do you notice?

19 You need worksheet 5-2 for this exercise.
The table on the worksheet lists the stopping distance and the braking time for various speeds.

a Draw the graph of the stopping distance against the speed.
b Use the graph to determine the speed at which a car has a stopping distance of 15 m.
c At a speed of 50 km/h, the braking distance is 14.4 m.
Use a calculation to show that the reaction time must have been 0.6 s.

***20** Read the text in figure 50.

a Explain why the speed of the bat is hardly reduced when it hits the ball.
b Use a calculation to show whether the force of ‘several thousand kilos’ mentioned in the text for a home run is really achieved. The mass of a baseball is 0.145 kg.

A hit with a bat takes less than a thousandth of a second and it involves forces of several thousand kilograms. To hit a homerun (and put the ball out of the stadium), the ball has to leave the bat with a speed of 170 km/h.

▲ **figure 50**
a fragment from an article about baseball

Waiting for a red traffic light. Go... stop... go... and then stop again for the next red light. For many car drivers, driving in a busy city is a daily torment. "If you have no luck, you end up standing still more than you're actually moving!" For traffic managers, our irritation is seen as a challenge: how can we keep the traffic flowing better, without compromising safety?

Working as a traffic manager

In a densely populated country such as the Netherlands, it's easy for the traffic to become congested. During the rush hour in particular, the volume of traffic can be huge. Bottlenecks in the road network inevitably lead to major delays. The job of a traffic manage is to think up smart solutions for this. The more efficiently the traffic can be dealt with, the shorter the time for which people will have to wait.

Plans for redesigning a road or crossroads can have a major impact. Thousands of road users – or sometimes many more – are affected and they all have an opinion about it. But you hardly ever hear anything about the people who develop the plans. All the more reason to go and talk to one of these planners. Traffic manager Aymee Prinsen (26) tells us about her work.

How do you get to become a traffic manager?

"I've always found traffic interesting. All those people, moving around every day: what's the best way of arranging that? Puzzling away at a problem until you've got the best possible solution – that's something I simply enjoy. When I had to choose my next course after completing secondary education, I didn't take long to make up my mind. I knew that I wanted to do something with traffic.

After secondary school, I took the *Built Environment* course at vocational college. You were able to choose from a variety of professional fields and graduation profiles there, and with my interest in traffic, I automatically ended up with mobility as the main field. I chose traffic management for the graduation profile, because I'm mainly interested in the technological side and I like solving concrete problems.

The course was very much practically oriented. You learn how to design a road, lay out crossroads and make sure that the urban traffic stays on track. You get theoretical courses too, but you're busy with projects for most of the

name	**Aymee Prinsen**
age	**26**
education	**secondary (havo), profile N+T vocational (hbo): Built Environment, profile: traffic manager**
job	**traffic management advisor**
plans	**to start her own consulting agency in ten years' time**

time. Then you work with a group of other students on a task for an external customer like a town council, who wants to improve traffic safety at a crossroads."

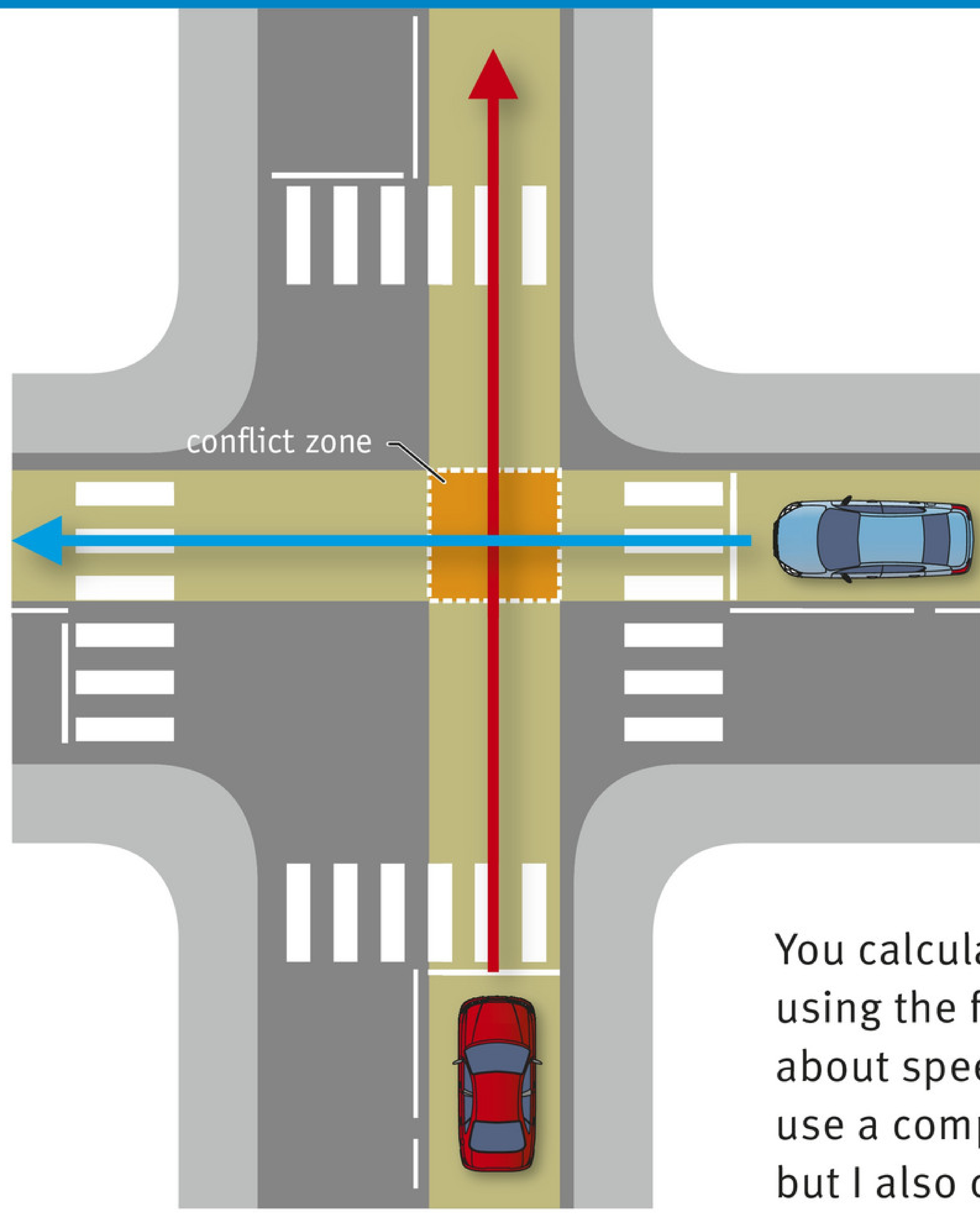
So what does your work involve?

"After the vocational course, I got a job as an advisor in a medium-sized consultancy agency. There are about twenty people there, five of them involved with traffic technology. I work on projects there such as optimising the layout of crossroads with traffic lights.

A project like that starts with me talking to a potential customer. If our agency gets the job, I first make a design. For instance, I will calculate how long the traffic lights have to be green and in what sequence, and how long the traffic then gets to clear the conflict zone – that's the jargon term for the area where the traffic flows cross.

Once the design is complete, I convert it into a computer program than turns the traffic lights on and off. I make that program in Visual C – a programming language – and test it using traffic simulation software.

During the installation of the traffic lights, I monitor everything on behalf of the town council to check that the plans are being implemented correctly. Once everything's there and the programs have been installed, the system is tested once again and then it's opened. That's always a tense moment, because you don't want anything to go wrong then, of course."

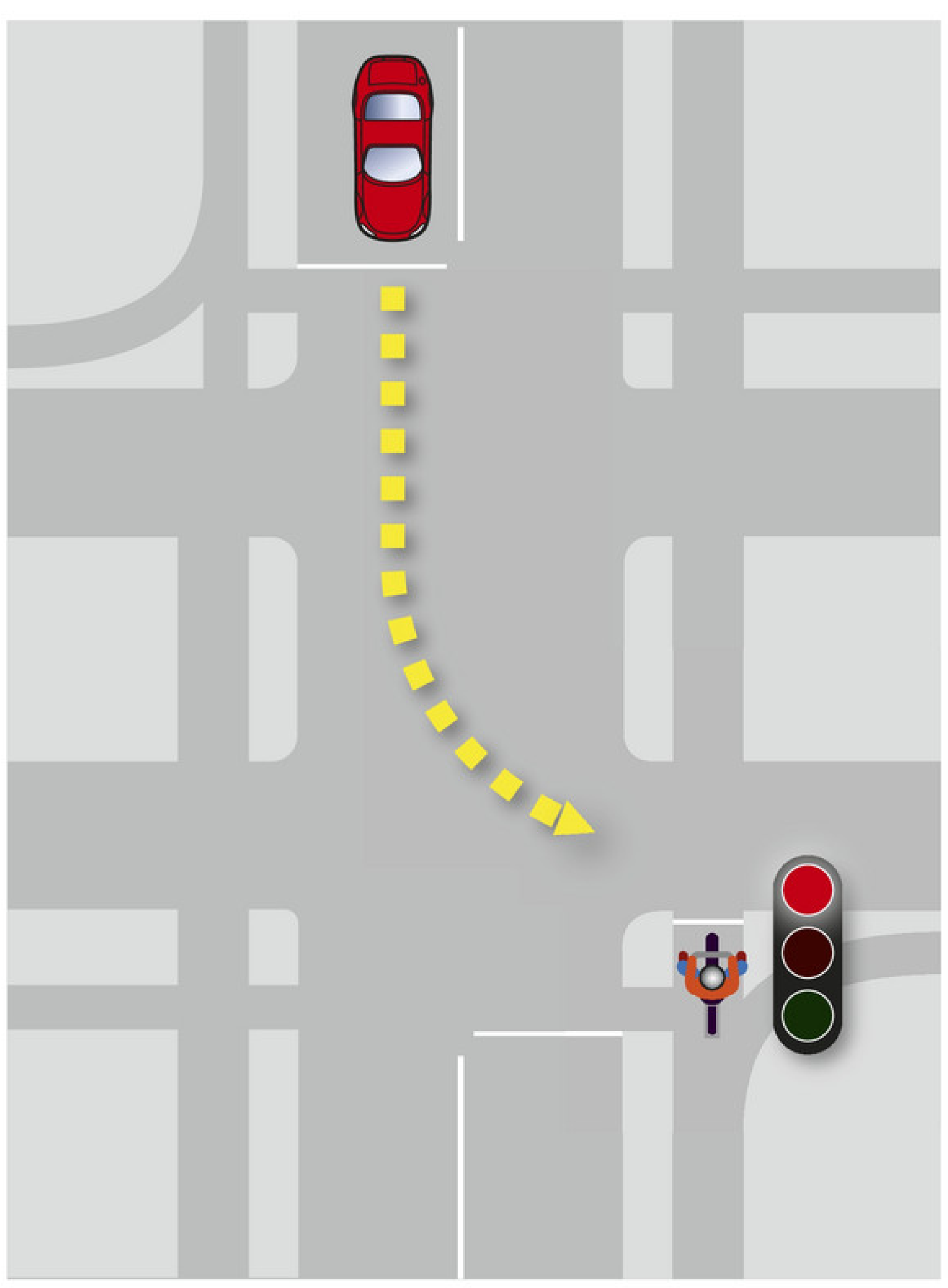


What role does physics play in your professional field?

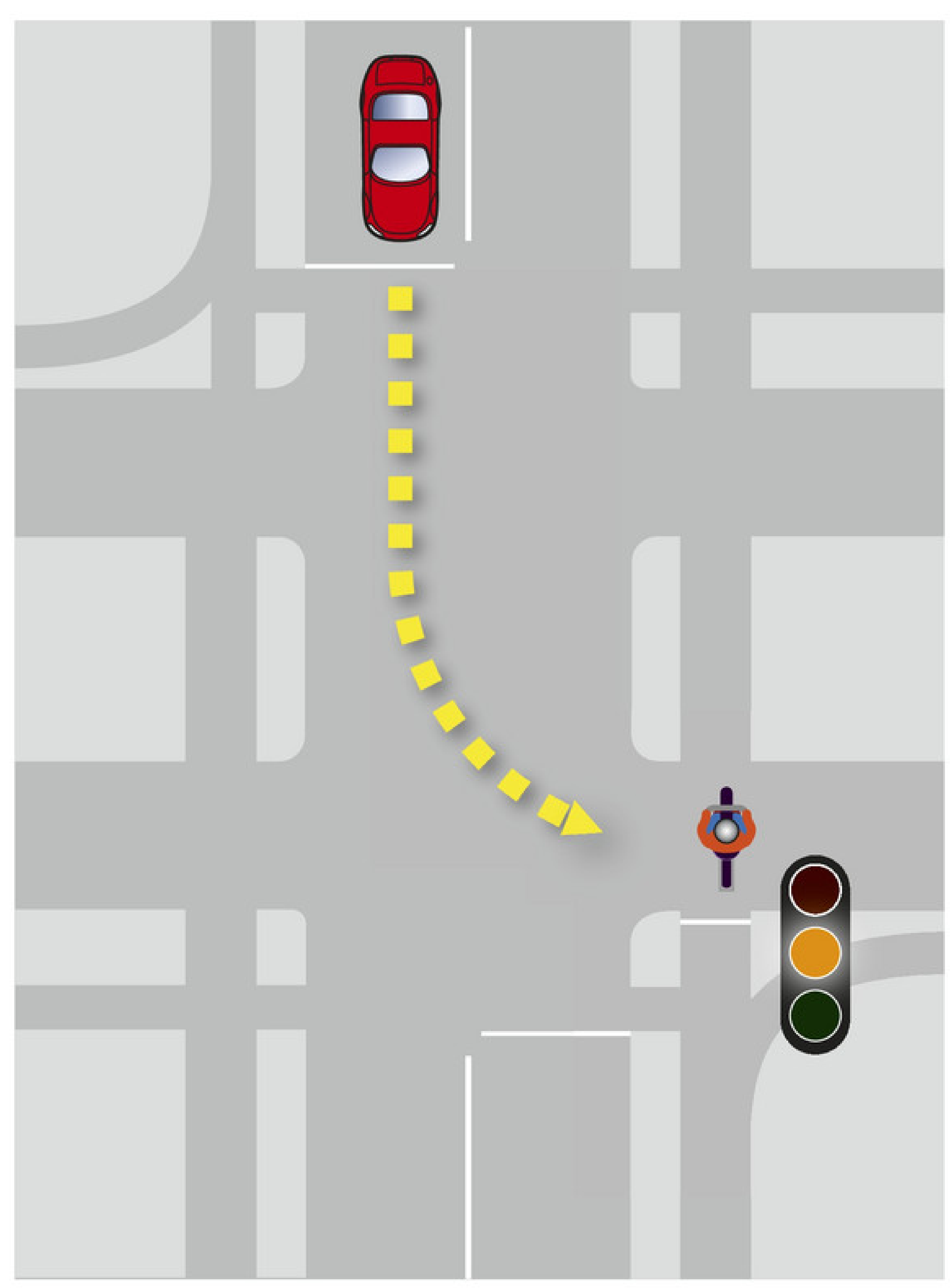
"When a traffic light goes orange, it takes a little while before the conflict zone is clear and traffic from another direction can drive across it. That's called the clearance time. As a traffic expert, you sometimes do have to calculate the clearance time, because it's different for every crossroads and for each type of road user.

You calculate the clearance time using the familiar physics formulae about speed and distance. I often use a computer to calculate things, but I also do calculations on a piece of paper, with a calculator. It's another way of convincing myself that everything is correct.

At school it doesn't matter too much if you make the odd mistake in your calculations, but in traffic technology it does. If you make a traffic light turn green too soon, it can cause accidents. Fortunately you usually do find the errors during testing, but there's always a risk. On top of that, correcting an



unnecessary waiting …



or driving through with intergroen

error in the software costs a lot of time and money."

Is your work challenging enough?

"Oh yes, definitely. Like any other company, we have to keep on innovating. Ideas about traffic flow and safety are always changing, and we have to move with the times. A good example is the norm for green at a set of traffic lights. For example, during my training I was taught that you must never give two directions a green light at the same time. If one direction has green the directions crossing it must have red.
Everyone actually knew perfectly well that this rule was too strict. Sometimes, driving up from where you have stopped up to the conflict zone can take a long time, whereas leaving the conflict zone can be very quick. You then end up with a negative clearance time: the conflict zone is empty before you need it to start emptying. There is now a brand new approach called 'intergroen' (intergreen) that makes use of that extra time. It allows the traffic lights for direction A to turn green while they are still green for direction B for a few moments."

"Intergroen only makes a couple of seconds' difference per cycle, but that can add up to quite a bit over the course of the whole day. intergroen is probably good for traffic safety too, because people are then less likely to run a red light. That's currently being investigated. Whatever, when intergroen is applied throughout the Netherlands soon, an agency like ours has to be ready for it. Because every second that we can trim off the waiting times is a second gained."

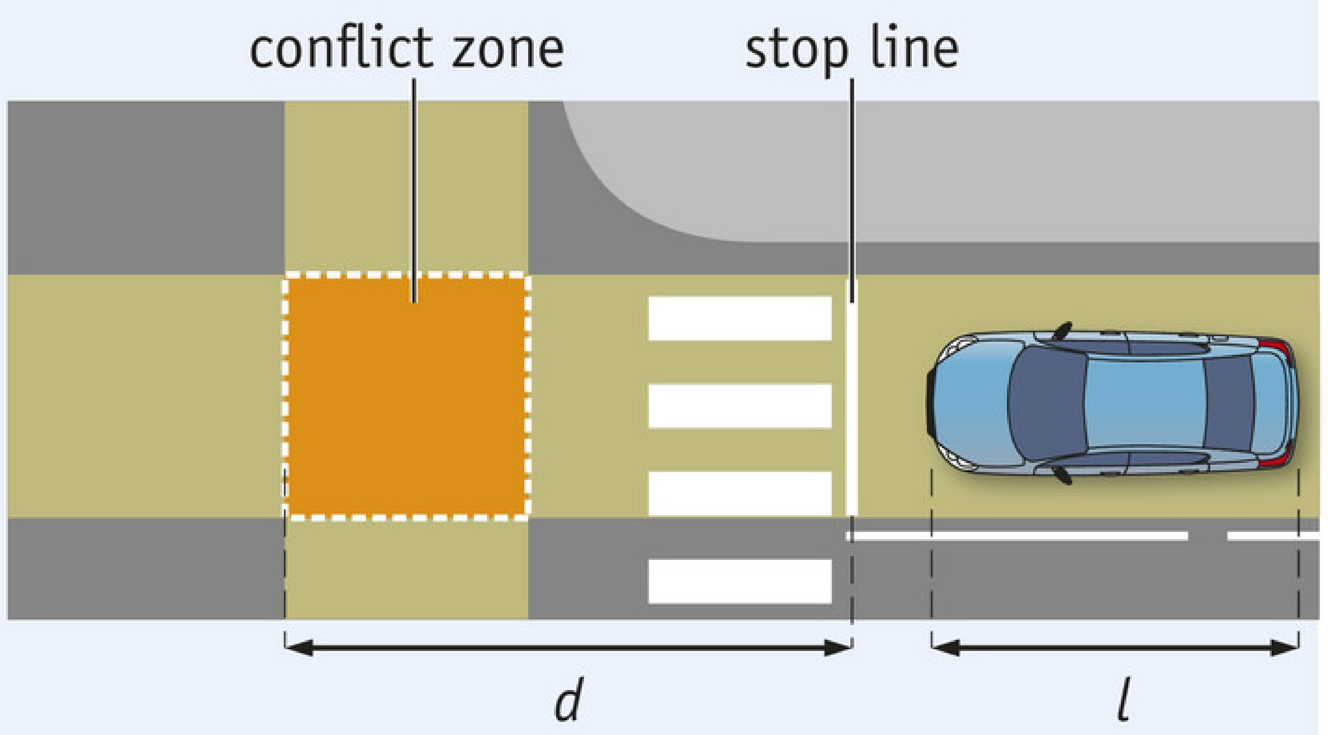
DID YOU KNOW...

In 2014, Grontmij and Rijkswaterstaat (the Directorate-General for Public Works and Water Management) studied the effectiveness of intergreen. The study showed that the number of vehicle-hours lost at crossroads was reduced by an average of 3.6% if intergreen was used. Over the Netherlands as a whole, that would save 4.9 million hours a time that vehicles lose while waiting every year.

Exercises

1 When a traffic light turns red, it takes a little while before the last car has left the conflict zone. The time this takes is called the clearance time (or exit time). The clearance time is calculated using the formula:

$$t_{out} = \frac{d + l}{v_{out}}$$



- **a** Use the drawing on the right to explain what the letters *d* and *l* mean.
- **b** Explain why it is important to include *l* in the formula.
- **c** How big is *l* for a car? And for a bus? Make an estimate.

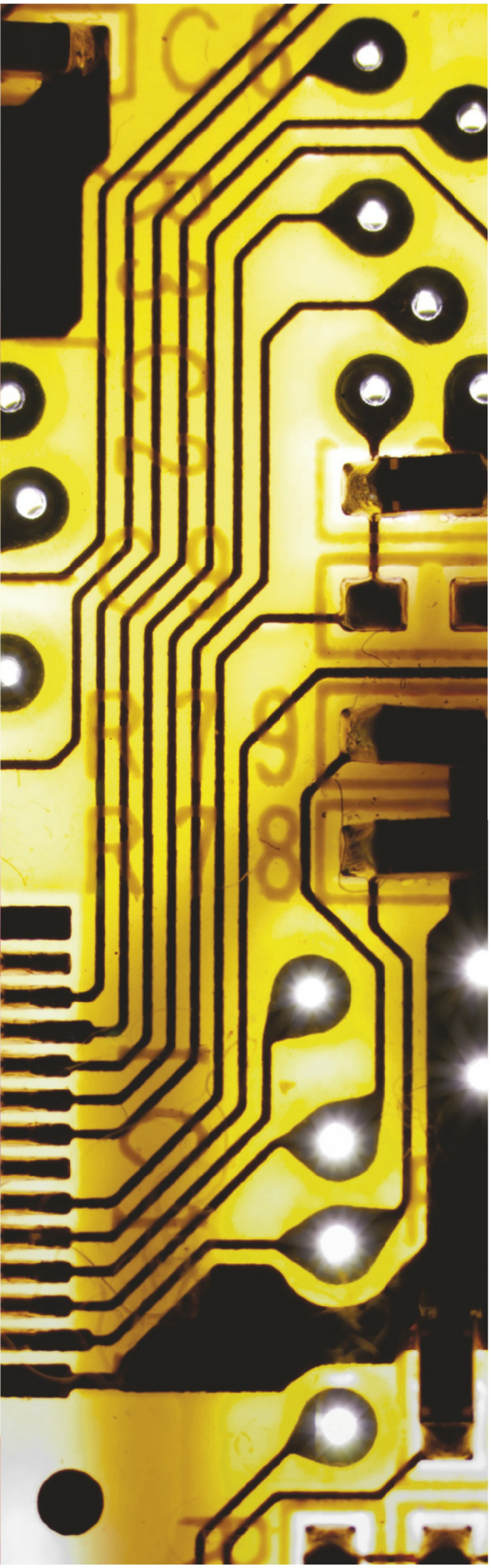
2 When a traffic light turns green, it takes a little while before the first car enters the conflict zone. The time this takes is called the entrance time. The entrance time is calculated using the formula:

$$t_{in} = \frac{d}{v_{in}}$$

- **a** Make a sketch of the situation, showing how you have to measure *d*.
- **b** Explain why *l* does not appear in this formula, although it does appear in the clearance time.

***3** Search the Internet for information about intergroen.
Write a short piece of text (one A4) explaining what intergroen is about and what its benefits and disadvantages are.


3
6
9
#



6

Circuits

Automatic control

A lot of devices have circuits that can detect things and react to them. These circuits let devices do their work independently. Examples of this are making coffee, selling soft drinks, setting off an alarm, controlling the temperature and opening or closing a door.

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1 Charge and voltage

When you take off a fleece sweater on a dry winter day you may hear it crackling softly. In the dark, you may even see sparks jumping across. The sparks are discharges of static electricity. Not dangerous under normal conditions, but still not really pleasant if the current runs through your body.

Charging objects

If you rub a PVC pipe with a woollen cloth, the pipe will then attract paper shreds. A fine stream of water is also attracted by the tube. We say that the PVC tube is **electrically charged** or **static** as a result of being rubbed.

▲ **figure 1**
Polystyrene balls are attracted by a comb that has been charged by rubbing.

There are various ways that you may notice that an object is charged:

- The object attracts other objects (figure 1). For example, you can see this because a lot of dust collects on the object.
- Sparks may jump across to other objects. You can hear this (as a soft crackling sound) and sometimes see or feel it.

A charged object mostly loses its charge quickly. The more water vapour is in the air, the more quickly the object discharges. Experiments with charged objects therefore work best if the air is very dry – the ideal conditions are if it is freezing outside and if the central heating is turned up high. The charge disappears too quickly in humid air.

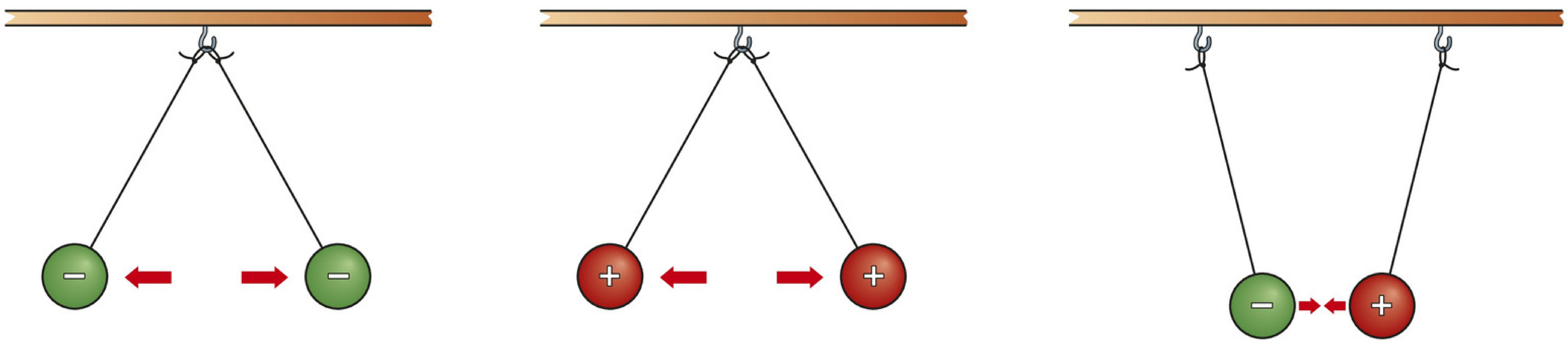
Positive and negative charges Experiment 1

If you rub a Perspex rod hard with a silk cloth, the rod will become charged. The same thing happens if you rub a PVC tube with a woollen cloth. However, there is a difference between the charges that were given to the two objects. Two charged Perspex rods repel each other. The same goes for two charged PVC pipes. But a charged Perspex rod and a charged PVC pipe attract each other.

You can repeat these experiments using objects and cloths that are made of different materials. You will then soon realise that there are two kinds of **charge**. Objects that have the same charge repel each other (figure 2). Objects that have different charges attract each other.

◀ **figure 2**
This is what happens to your hair when all the hairs get the same charge.

One type of charge is called **positive** (plus) and the other type is called **negative** (minus). A Perspex rod that has been rubbed with a silk cloth has a positive charge. A PVC tube that has been rubbed with a woollen cloth gets a negative charge. Two positives repel each other, as do two negatives, but a positive and a negative attract each other (figure 3).



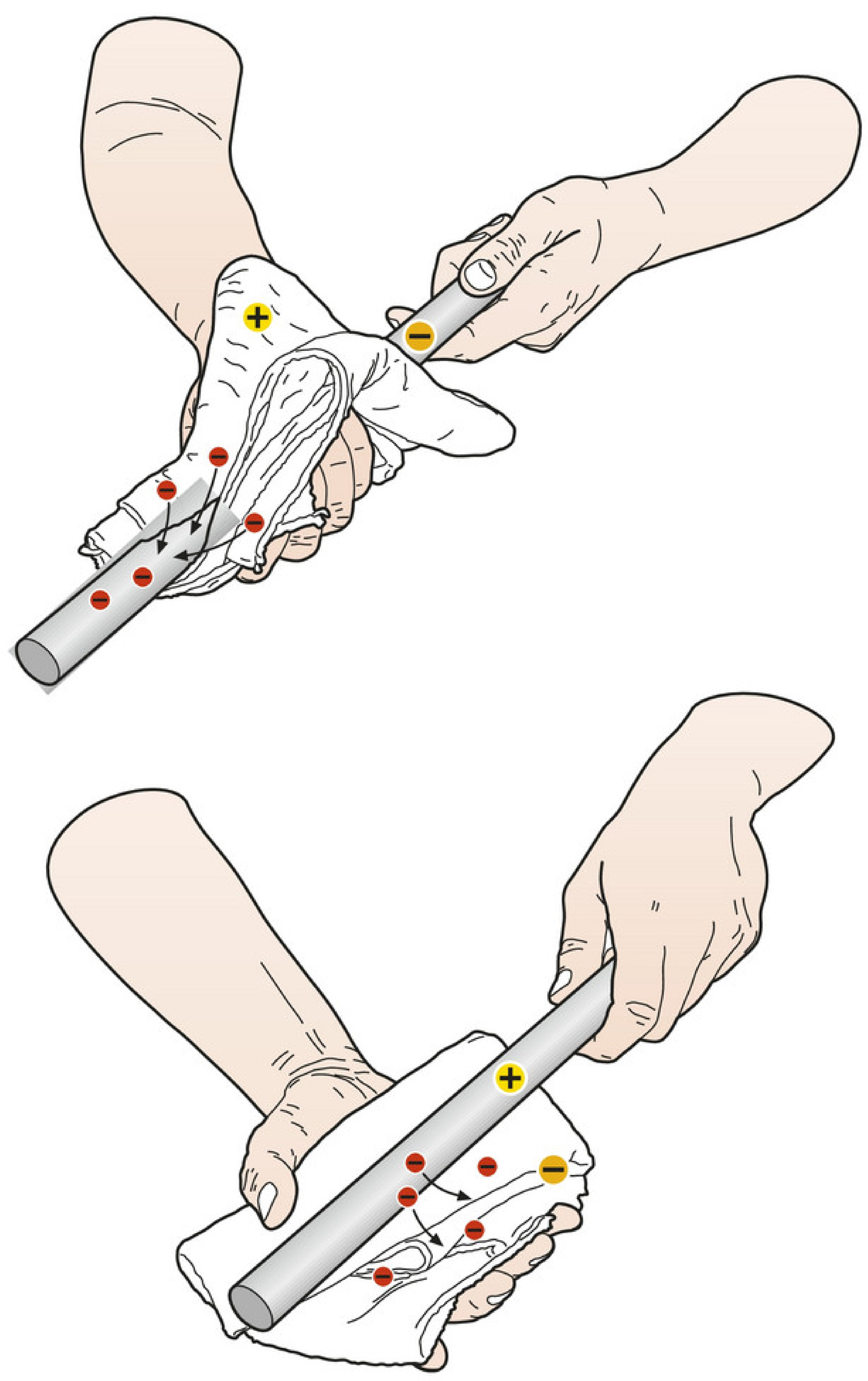
▲ **figure 3**
attraction and repulsion

Electrons

An uncharged object contains exactly the same amount of positive charge and negative charge. You therefore do not notice that such an object contains any charges. In that case, we say that the object is **neutral**.

If you rub an object with a cloth, small, negatively charged particles can 'jump across' from the cloth to the object or the other way round. These particles are called **electrons** (figure 4). There are also positively charged particles, but they cannot move from one object to the other. When you rub the object, you therefore always move a negative charge around (and never a positive charge).

If the electrons from the cloth jump across to the object, the object will have a larger amount of negative than positive charge after that, it is then negatively charged. Conversely, the cloth has lost electrons and therefore has an equally large, positive charge. When the electrons jump across from the object to the cloth, the reverse will happen. In that case, the cloth becomes negatively charged and the object positively charged.

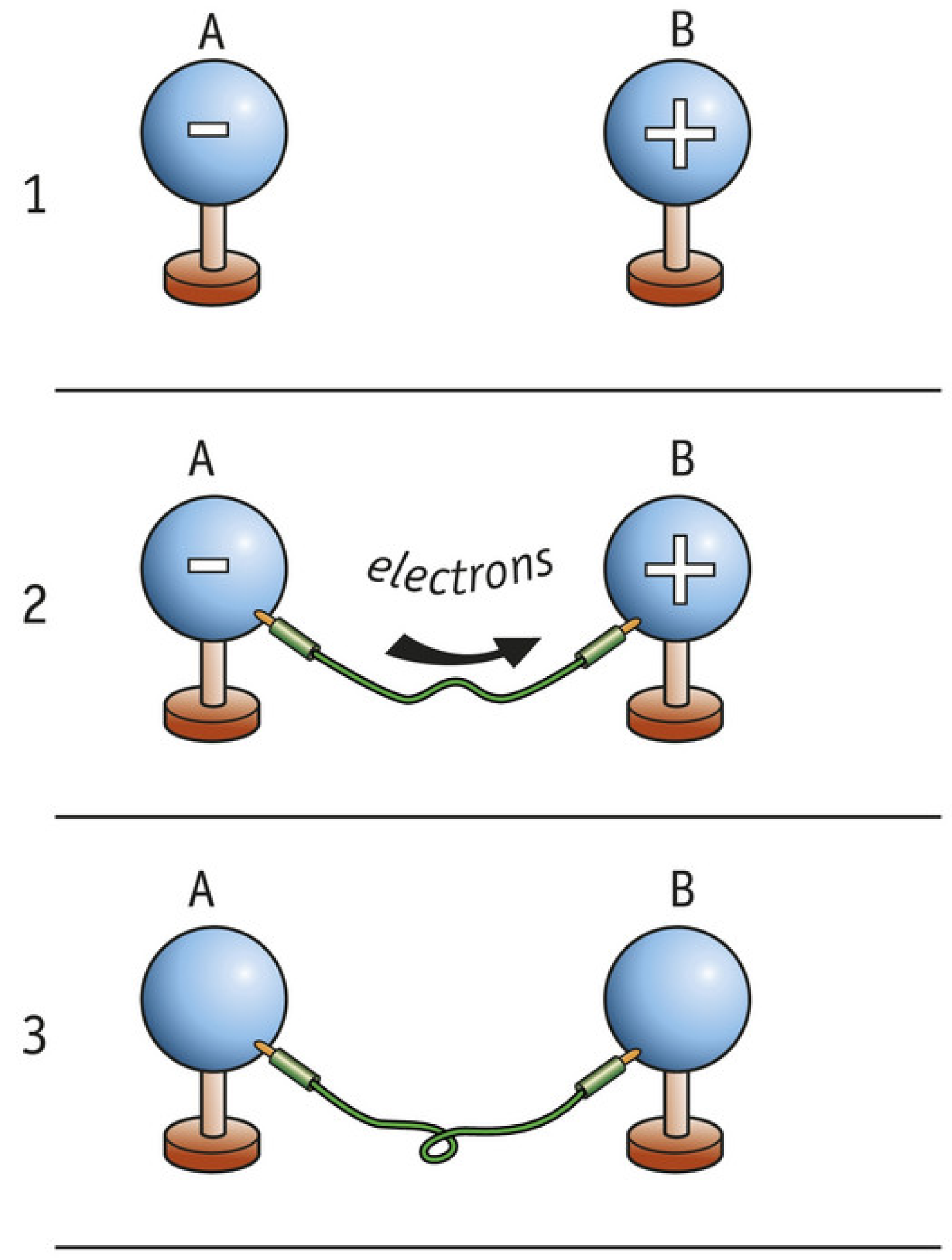


▲ **figure 4**
Rubbing makes electrons move.

Voltage and electrons

Figure 5 shows two equally large metal balls on plastic stands. Ball A is negatively charged and ball B is positively charged. In such a case, we say that there is a **voltage difference** between A and B. When you make a connection between A and B that is made of a conductor, electrons start to move from A to B. An electric current runs from A to B.

The current between A and B only flows for a very short while. This is because there will very soon be no voltage between A and B anymore; both balls then have the same charge. A charged object can also discharge when a spark jumps across to something (or someone) else. This also only lasts for a moment, the charged object loses its charge in just a fraction of a second.



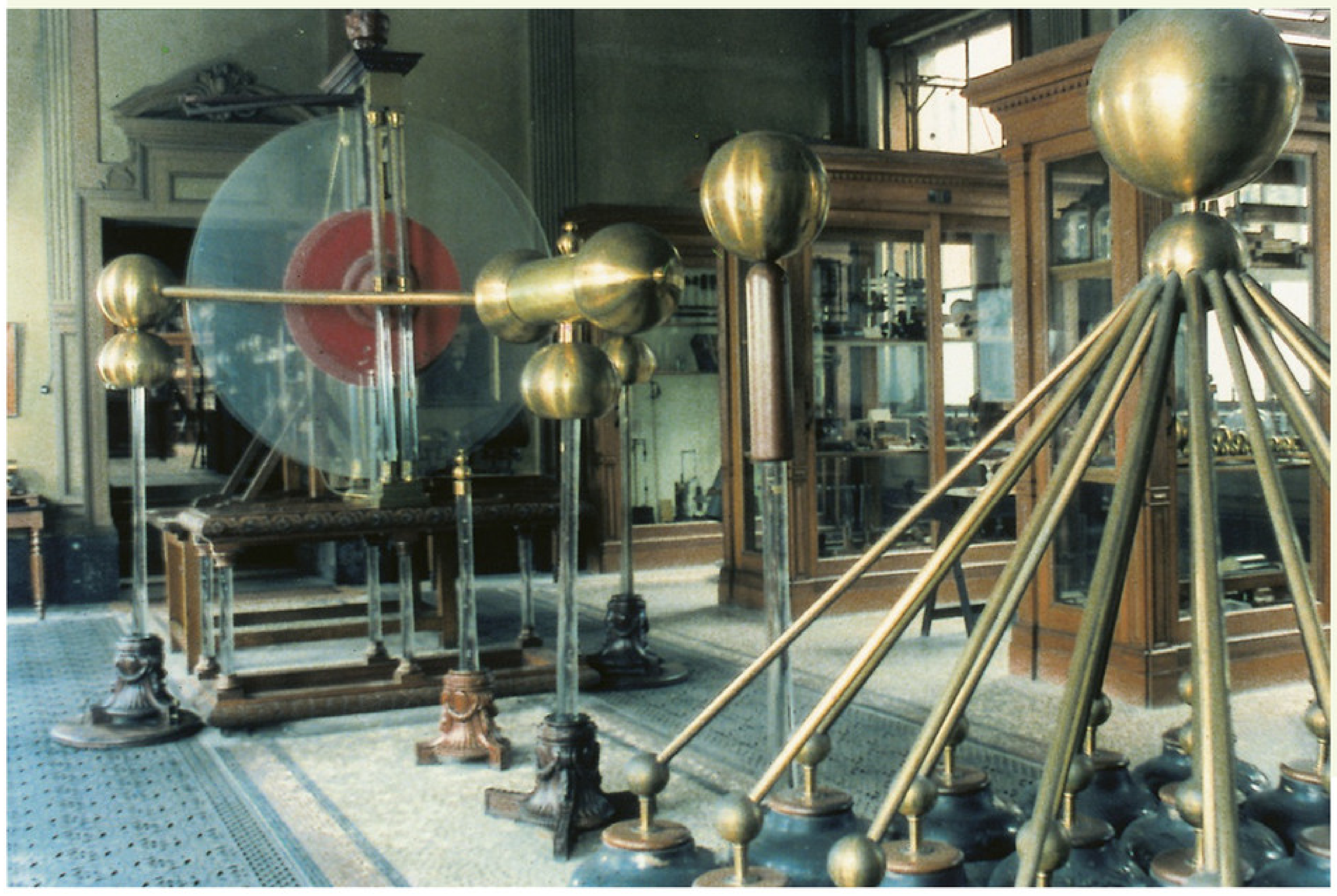
High voltages between charged objects and their surroundings may make sparks jump across. For instance, a car can accumulate a voltage of up to 3000 V while driving along.
When you get out of the car, you notice it, you feel a slight shock as the car discharges through your body. Such a shock is not dangerous because the current only flows through your body for a very short while.

A voltage source is needed if a current is to flow for a longer period. That is why you use dynamos and batteries in daily life instead of objects that are charged by rubbing.

◀ **figure 5**
Electrons move from minus to plus.

Plus Electrifying machines

An electrifying machine (a static electricity generator) is a device that can give an object a substantial electric charge. This can generate high voltages. Various kinds of static electricity generators were designed in the seventeenth and eighteenth centuries. They were used to create large sparks and to carry out amusing experiments. These types of experiments are still carried out in schools, using an electrifying machine or a belt-driven generator.



One of the largest electrifying machines was made in 1784 by Martinus van Marum (1750–1837; figure 6). This device is now displayed at the Teylers museum in Haarlem (Netherlands). The entire machine is more than ten metres long. On dry winter days, Van Marum could create sparks of up to half a metre long with it.

◀ **figure 6**
Van Marum's static electricity generator

exercises

1 You can charge a PVC tube negatively by rubbing it with a woollen cloth.

a Explain why the tube becomes charged.
b What are the particles called that jump across from one object to the other?
c Do these particles jump from the pipe to the cloth or the other way round?
d Why can the positive particles not jump across?

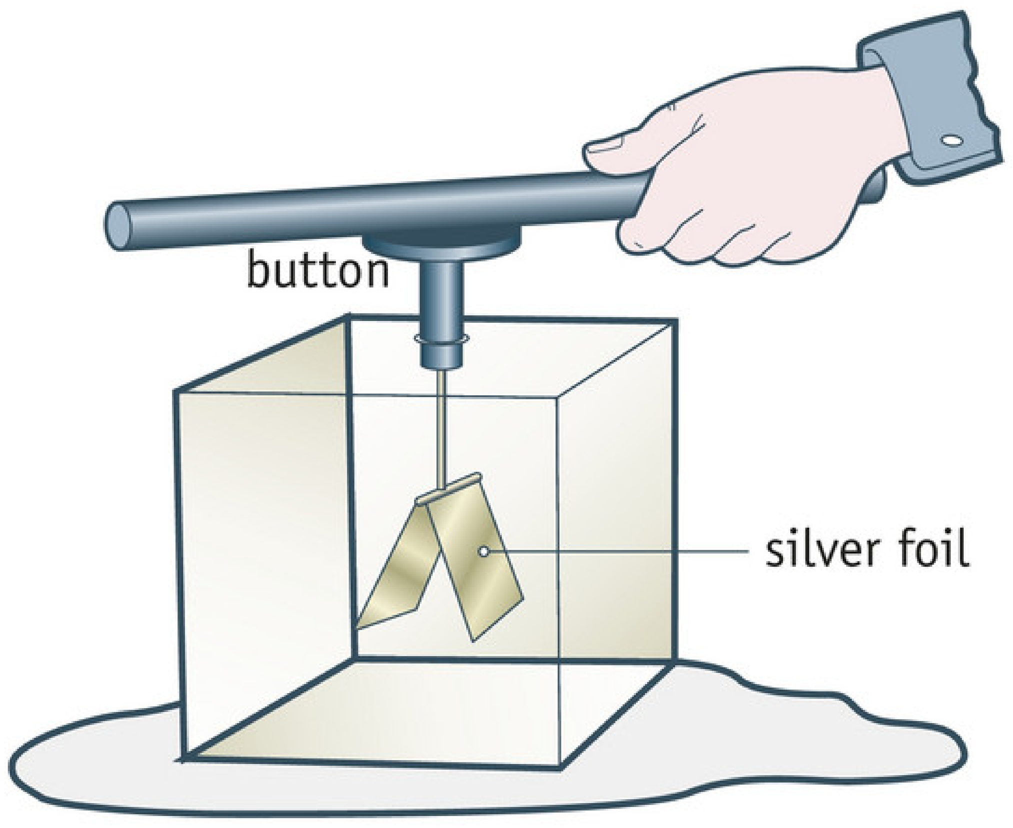
2 Answer the questions below.
a How can you tell when an object is electrically charged?
b Why do experiments with charged objects often not work when it is raining?
c What do you know about the amount of charge in a neutral object?
d Sometimes you feel a shock when you get out of the car after a drive. Why?

3 The air humidity is very low in clear, freezing weather. You may then notice very clearly that objects get charged electrically by friction (rubbing).
In what way (or ways) might you notice:
a that your hair and comb get charged when you comb your hair?
b that a fleece sweater has become charged when you take it off?
c that a strip of sticky tape is charged when you pull it from the roll?

4 You need worksheet 6-1 for this exercise.
Kevin hangs two table-tennis balls on a nylon thread. A few seconds later, the tennis balls are not moving anymore. See the drawing on the worksheet.
Kevin says, “The two balls have the same kind of charge on them.”
Dennis says, “One ball is charged but the other one isn’t.”
Peter says, “The two balls are not charged at all.”
a Who is right, and why?
b In boxes b and c, draw what you would see in the other two cases.
c For each of the drawings, state which boy described this situation.

▲ **figure 7**
The driver of the tanker unrolling the earth cable.

5 During a flight, a plane can become charged by friction with the air. Explain:
a why the electrical charge could be a hazard when the plane is being refuelled after landing.
b why the risk of an accident is greatest in winter, particularly when it is freezing at the airport.
c why you have to connect the plane to the tank truck first with a metal ‘earth cable’ before refuelling (figure 7).
d why the clamps of the ‘earth cable’ must make a good contact with the metal frame of the plane.

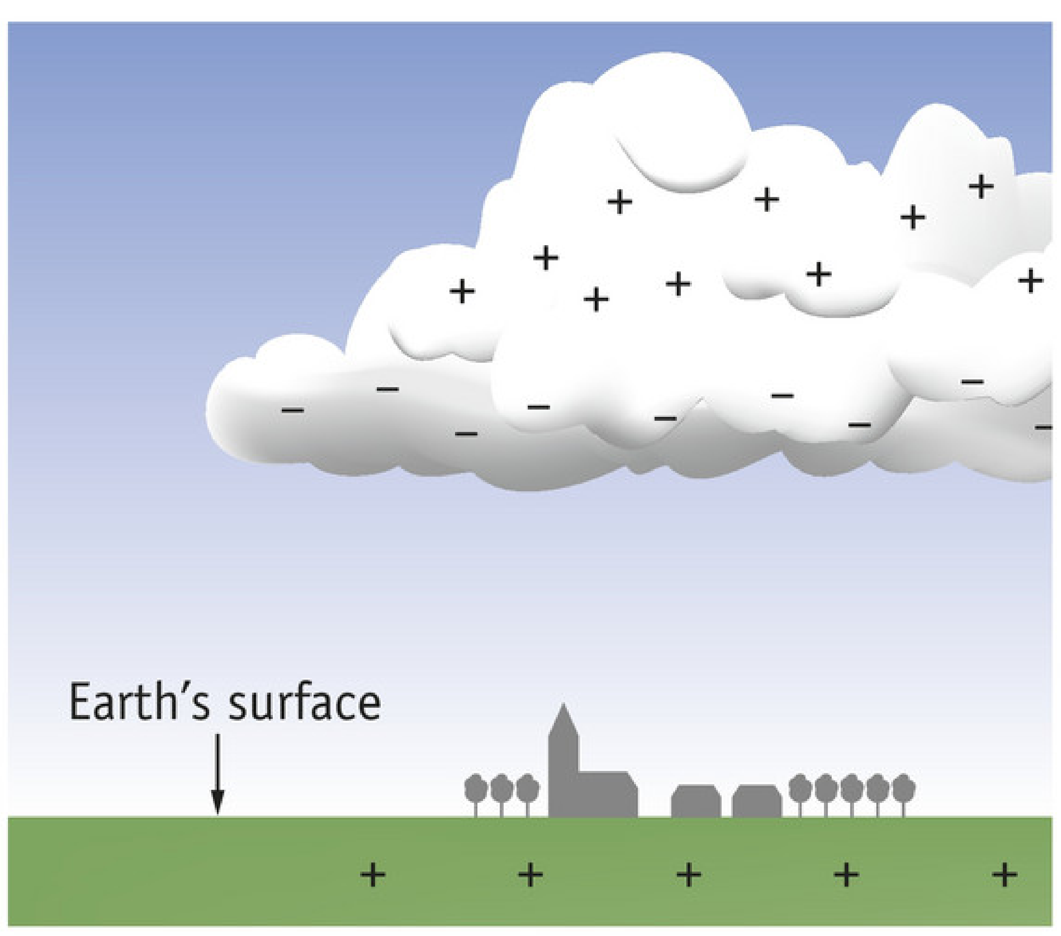


▲ **figure 8**
an electroscope

***6** Figure 8 shows an electroscope. You can use this device to check if an object is charged. If you press a charged object against the button, the two pieces of silver foil move apart.
a Explain why.
b Can you tell from the result of the electroscope if the object is positively or negatively charged? Explain.
c Explain how you can tell from figure 8 that the rod must have been made of an insulating material.
d If you move the rod along the button, the pieces of silver foil will move further away from each other.
Give an explanation for this.

Companies are choosing powder coating for treating surfaces more and more often. This is because powder coating gives better results in terms of the coating, finish and gloss than the conventional methods. The electrostatic effect caused by positively charging the powder particles makes sure that all edges and the parts that are difficult to reach are powder coated.

▲ figure 9
powder coating metal components



▲ figure 10
the distribution of charges in a thunder cloud

7 Mary connects the button of a positively charged electroscope A to an equally strong negatively charged electroscope B using a conducting wire.
- **a** What happens to the results of both electroscopes?
- **b** Describe what has happened after the two electroscopes have been connected.

8 On a company website, Ron reads that powder coating is becoming more and more popular (figure 9).
Explain:
- **a** why the components that are being coated must be negatively charged beforehand.
- **b** why it is important that every powder particle in the coating has a positive charge.
- **c** why powder coating gives better coating in 'difficult spots' than normal paint.

***9** There is a high voltage between the underside of a thundercloud and the Earth. Air is an insulator, but if the voltage is too high, a spark from the cloud can jump across to the ground. These sparks are called lightning.
- **a** The combination thundercloud-Earth is not a voltage source suitable for practical purposes. Why is that? Write down two reasons.
- **b** Estimate how high the underside of the thundercloud in figure 10 is above the ground.
- **c** Lightning can jump across when the voltage is more than 1.6 MV (megavolts) over a distance of 1.0 m.
  Calculate the voltage between the cloud and the Earth when there is lightning.
- **d** Explain why lightning also jumps within a cloud during a thunderstorm.

Plus Electrifying machines

10 Van Marum's original static electricity generator could generate a voltage of 300 kV. That could only be done on dry days.
- **a** Explain why this could not be done in humid weather.
- **b** Why can you only generate 'single' sparks with it and not a continuous high current?

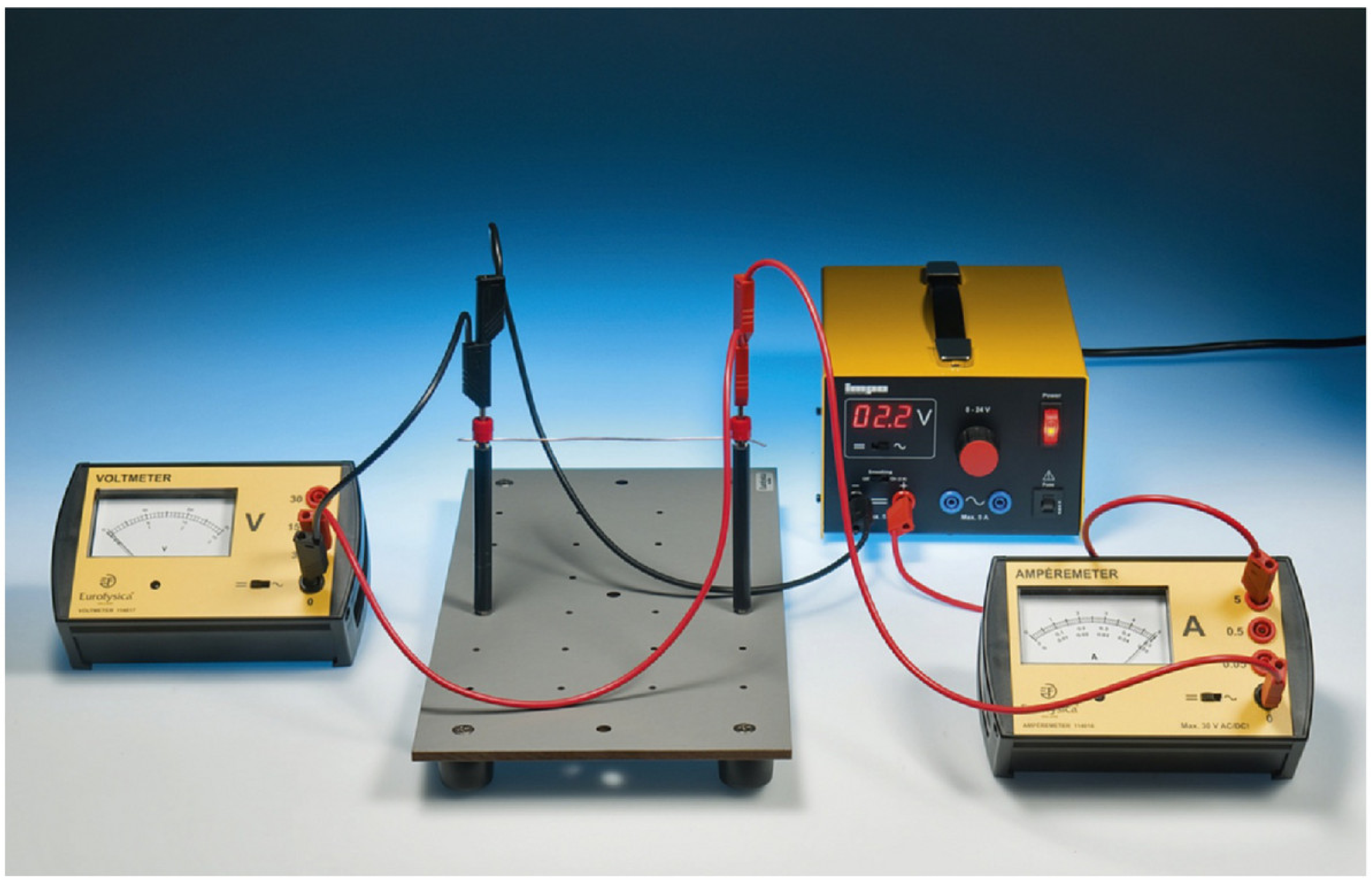
11 Sasha generates a voltage of 10 kV with a static electricity generator. The ball of the electrifying machine is positively charged. When she gets too close to the ball with her finger in the dark, she feels a shock and sees a spark between her finger and the ball.
- **a** Explain how the electrons have moved during that spark.
- **b** Although the voltage is 10,000 V it is much less dangerous than if you touch a wire in the domestic electricity supply.
  Explain why.

2 Resistance

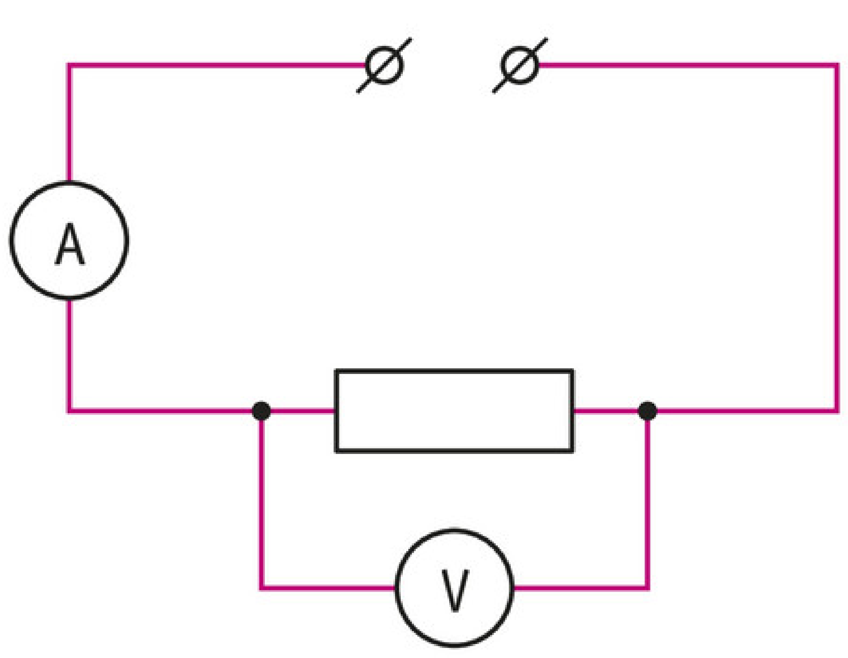
There are all kinds of appliances in your home that work on 230 V mains voltage. The amount of current that runs through those appliances can vary a great deal. For instance, the current through a tumble dryer is much greater than the current through an electrical alarm clock. It would seem that there is less resistance in the tumble dryer to the flow of electrons.

Calculating the resistance

With the setup in figure 11 you can measure the relationship between the voltage *across* a wire and the current *through* the wire. The 'voltage across a wire' means the voltage difference between the two ends of the wire. Figure 12 shows the diagram for the circuit.



▶ **figure 11**
How to determine the resistance of a wire.



▲ **figure 12**
the circuit diagram for the circuit in figure 11

If you carry out this experiment with various wires, you will notice that the differences are large, some wires need a high voltage to 'force' a small current through the wire. Such a wire has a high **resistance**, it is difficult for current to flow through it. There are also wires where a low voltage creates a large current. These wires have a low resistance, it is easy for current to flow through them.

You can therefore define the resistance of a circuit component using the voltage (across the component) and the current (through the component). According to that definition, the resistance is equal to the voltage divided by the current. This gives you a useful numeric value for the resistance. As a formula:

$$R = \frac{U}{I}$$

If you give the voltage U in volts (V) and the current I in amps (A), this gives you the resistance R in ohms (Ω). The unit of resistance is named after the German physicist Georg Simon Ohm.

Worked example 1
The packaging of an LED bulb says 12 V/100 mA.
Calculate the resistance of the bulb if it is lit at the right voltage.

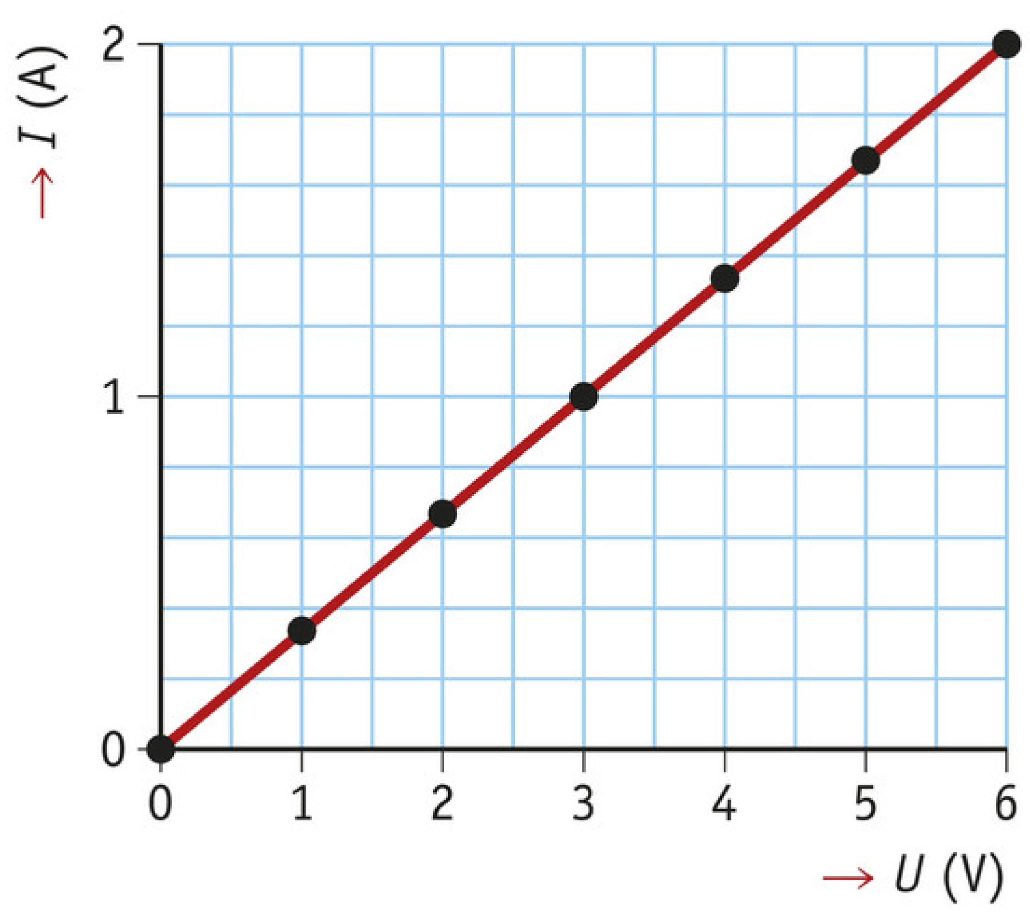
data $U = 12$ V
$I = 100$ mA $= 0.1$ A

required $R = ?$

working $R = \dfrac{U}{I} = \dfrac{12}{0.100} = 1.2 \cdot 10^2\ \Omega$

Ohm's law Experiment 2

You can use the setup in figure 12 to carry out a series of measurements in which you increase the voltage more and more. The results of such an experiment are drawn in figure 13. The experiment uses a wire of the metal constantan (an alloy of copper, nickel and manganese). In the graph, the current has been plotted against the voltage. Such a graph is called an **(I,U) diagram**.



▲ **figure 13**
the (I,U) diagram of a constantan wire

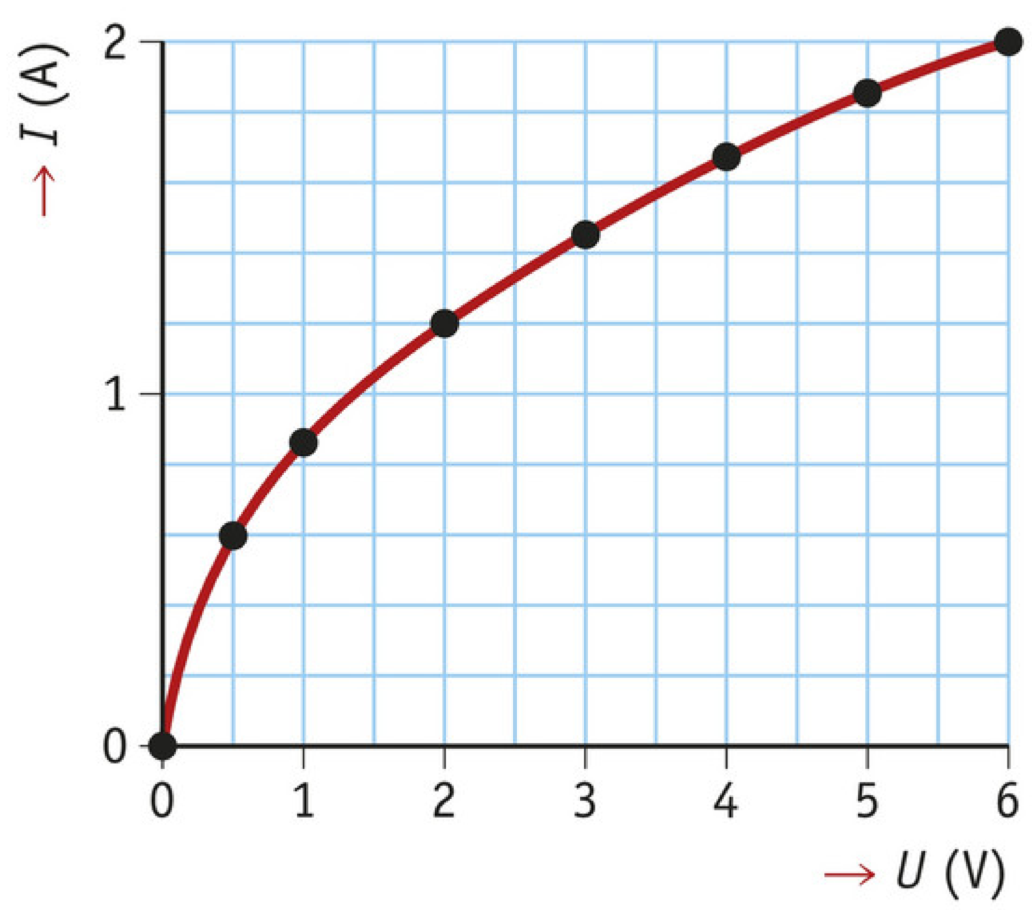
You see:
- if the voltage becomes 2× as large, the current will become 2× as large too;
- if the voltage becomes 3× as large, the current will become 3× as large too;
- and so forth.

In other words:

The voltage (across the wire) and the current (through the wire) are directly proportional.

This rule is called **Ohm's law**.

Ohm's law shows that the resistance of the wire has a constant value. If you divide the voltage U by the current I, this always gives the same number.



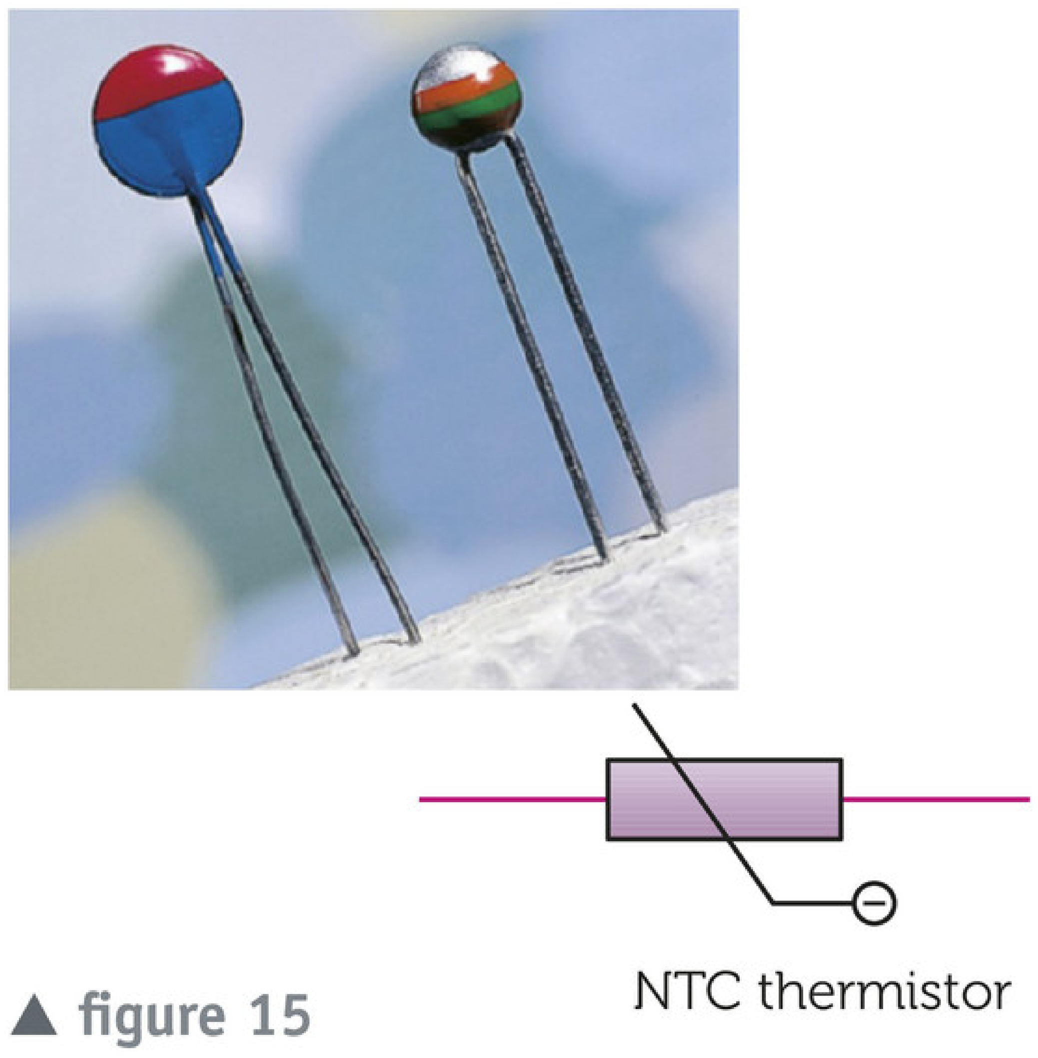
▲ **figure 14**
the (I,U) diagram of an incandescent bulb

Resistance and temperature Experiment 3

If you measure the relationship between the voltage and the current for an incandescent bulb, you will get a different result. You can see that in the (I,U) diagram in figure 14. The voltage and the current are not directly proportional any longer. If the voltage becomes 2× as large, the current clearly does not increase so rapidly. In that case, Ohm's law does not apply.

The cause of this difference is the high temperature of the filament. As the voltage across the filament increases, the bulb will light up more and more brightly. The temperature of the filament rises a lot, up to as much as 2500 °C. The resistance of the filament increases significantly at such high temperatures.

Almost all types of wires will have a higher resistance when their temperature increases. Constantan wires are an exception, their resistance is constant, even if they become much hotter. Even so, you can often assume that other wires have a constant resistance too. If the temperature rise is limited – which is mostly the case in practice – then you can ignore the increase in resistance.



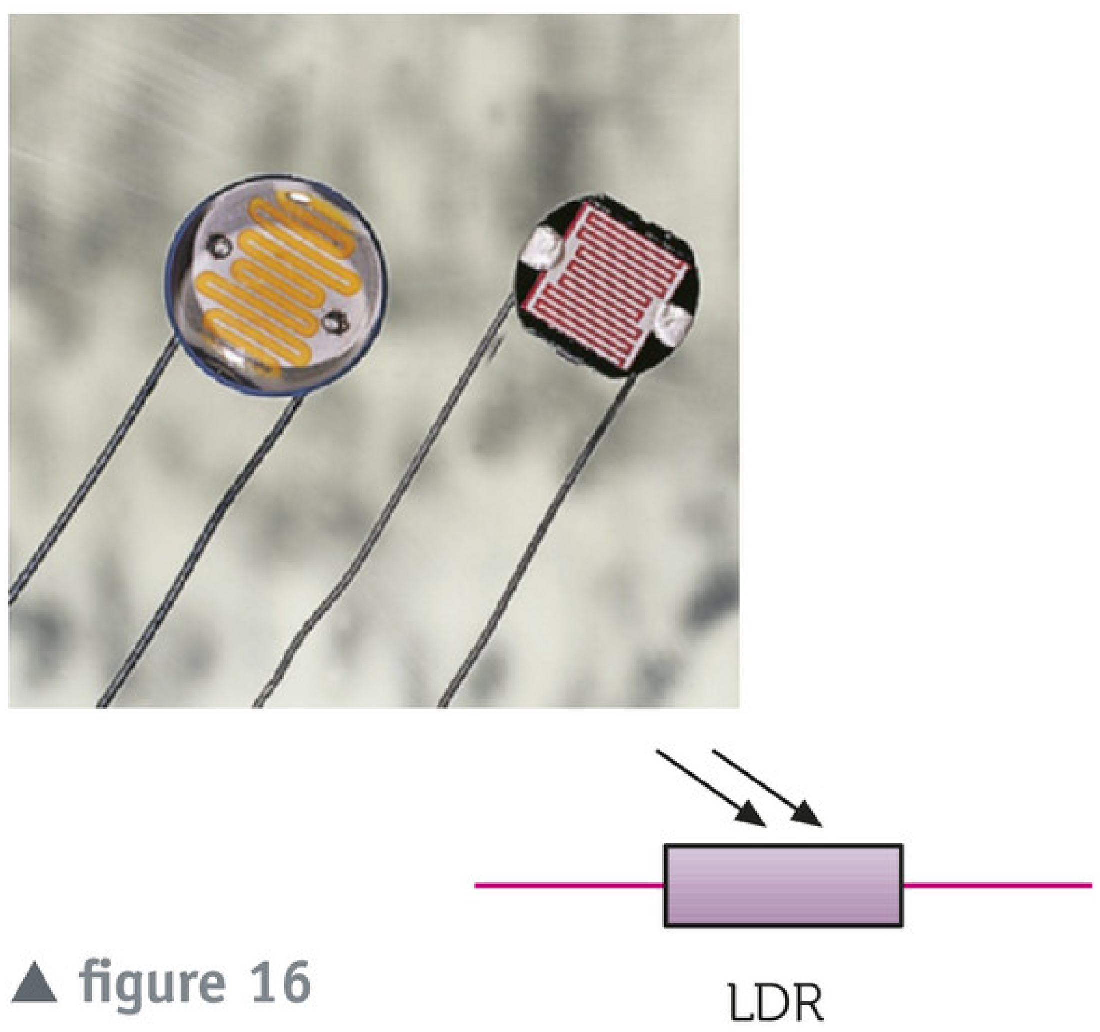
▲ **figure 15**
two NTC thermistors and the circuit symbol (below)

NTC thermistors and LDRs

Circuits sometimes use components with variable resistors. Two examples are the **NTC thermistor** and the **LDR**.

- An NTC (negative temperature coefficient) thermistor (figure 15) is sensitive to changes in temperature. As the temperature of an NTC thermistor increases, its resistance becomes lower. The NTC thermistor will conduct much better then and pass more current.
- An LDR (light-dependent resistor, figure 16) is sensitive to changes in the amount of light. If more light falls on an LDR, its resistance will be lower. The LDR will conduct much better then and pass more current.

These variable resistors are widely used in automatic circuits, the NTC thermistor as a temperature sensor and the LDR as a light sensor.



▲ **figure 16**
two LDRs and the circuit symbol (below)

Plus The resistance of your body

If you touch a conductor that is at a high voltage ('live'), the current will try to find a way to the Earth through your body (figure 17). How large the current will be depends on the voltage and the resistance that the current encounters on its way. The resistance is the sum of the body's resistance and the contact resistance.

Young boy almost electrocuted

Haarlem – A seven-year-old boy from Haarlem was severely injured last Friday afternoon after trying to swing on the overhead line of a railway. The boy, who had climbed on the roof of a high goods wagon at the railway yard in Haarlem together with his five-year-old brother, jumped at the high voltage wire. As he did so, he touched both the overhead line and the wagon and received an electric shock. He was taken to hospital with severe burns.

The human body is a good conductor of electrical current. The body's resistance therefore is not very high, somewhere between 100 and 500 Ω. The current will encounter more resistance at the points where the body touches the conductor and the Earth. The contact resistance can be more than 100 kΩ if the skin is very dry.

If the skin is wet, the contact resistance will become very low, only 1000 Ω, 100 times less than when the skin is dry. The moisture provides a much better contact between the body and the conductor or the Earth. Because the resistance is lower the current will become greater, which increases the risk of accidents. That is why you must be very careful with electricity in the bathroom.

◀ **figure 17**
High voltages are life-threatening.

exercises

12 Answer the questions below.

- **a** What formula can you use to calculate the resistance of an electrical component?
- **b** What does Ohm's law say about the relationship between voltage and current?
- **c** What is the special property of wires that are made of constantan?
- **d** Why does Ohm's law not apply to the filament of an incandescent bulb?
- **e** Which electrical component has a lower resistance as its temperature rises?

13 Copy table 1 and fill in the missing data.

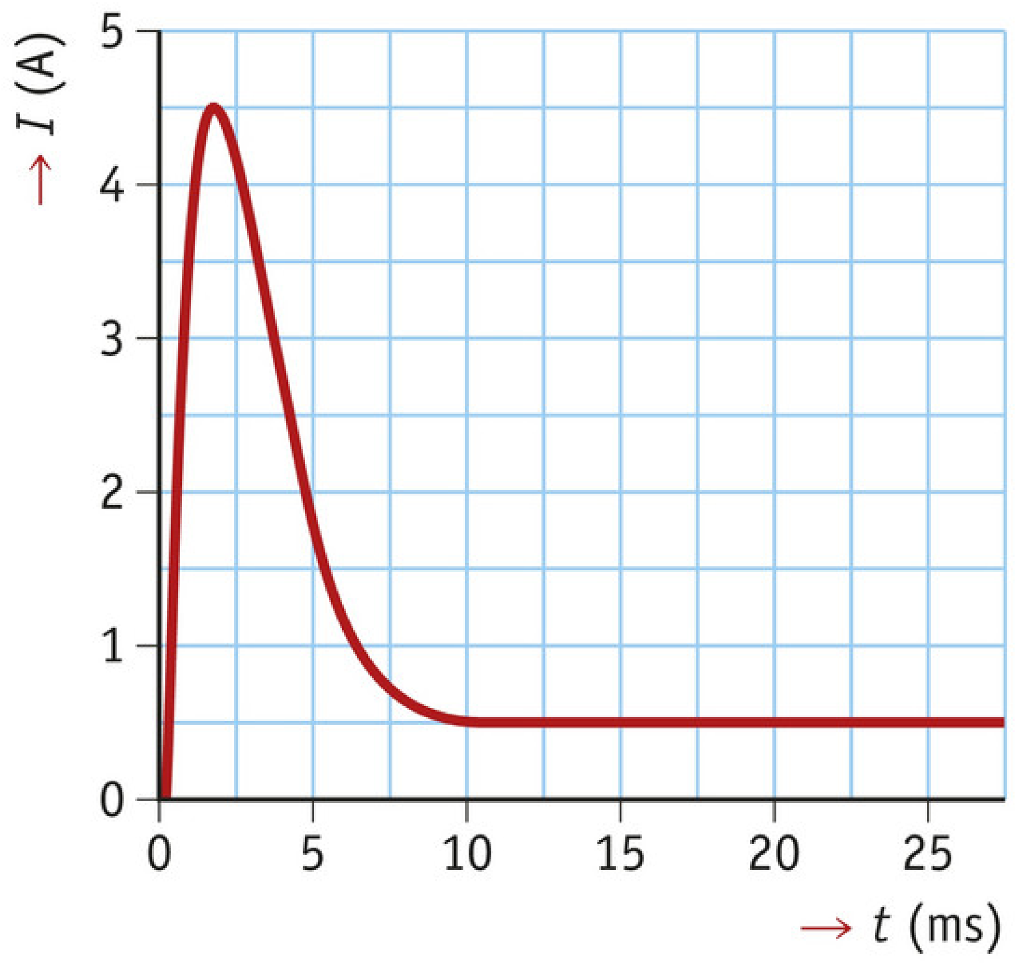
▼ **table 1** various variables and their units

variable	symbol	unit	symbol
voltage			
	I		
		ohm	

14 You need worksheet 6-2 for this exercise.
Ally wants to measure the resistance of a bicycle light. On the worksheet you can see the things she has got ready for this.
- **a** Complete the circuit by drawing the missing wires.
- **b** After that, draw the corresponding circuit diagram in the box.
- **c** Ally builds the circuit and carries out the experiment. On the voltmeter she reads off a voltage of 6.0 V and on the ammeter a current of 0.23 A.
  Use this data to calculate the resistance of the bulb.

15 A mixer, a light and a kettle are connected to the mains (230 V).
- A current of 1.4 A goes through the mixer.
- A current of 48 mA goes through the light.
- A current of 9.6 A goes through the kettle.

Calculate the resistance of each device.



▲ **figure 18**
the graph of Peter's experiment

***16** In an experiment, Peter lights a bicycle light using a battery (4.5 V). His setup for the measurement is connected to a computer. After the experiment, he gets the computer to draw a graph of the first 25 ms after switching on the power (figure 18).
- **a** How can you tell that the resistance of the filament was not constant?
- **b** Calculate the resistance of the filament at the maximum current.
- **c** Why does the current decrease strongly after that?
- **d** Calculate the resistance of the filament at constant current.

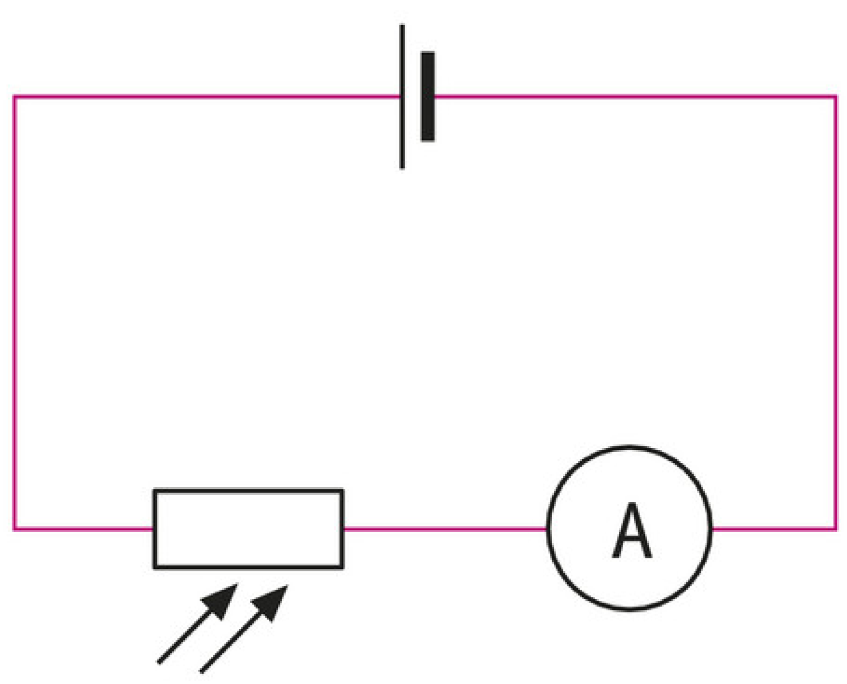
17 Lars has connected a constantan wire of 6.0 Ω to a power supply box. He measures a current of 0.25 A.
- **a** Calculate what voltage Lars has set the power supply box to.
- **b** Lars turns the adjuster knob of the power supply box until the ammeter shows 0.75 A.
  Calculate what the voltage is now.
- **c** Check your answer to b with a calculation.

▼ **table 2** Angie's measurements

voltage (V)	current (A)
2.0	0.18
4.0	0.26
6.0	0.32
8.0	0.37
10.0	0.41
12.0	0.44

18 Angie has lit an incandescent bulb at different voltages. She has measured the current each time. These measurements are given in table 2.

- **a** Use Angie's measurements to make an (I,U) diagram.
- **b** The resistance in the bulb changes as the bulb starts to light up more brightly.
  How can you tell this from the graph?
- **c** Using the information in the graph, explain whether the resistance increases or decreases when the bulb starts to light up more brightly.
- **d** Calculate the resistance of the bulb at a voltage of 7.0 V.
- **e** Using the information in the graph, explain whether Ohm's law works for this bulb.



▲ **figure 19**
the circuit diagram for Rick's light meter

19 Rick is building a simple light meter in a practical (figure 19). The battery of the meter delivers a voltage of 3.0 V.

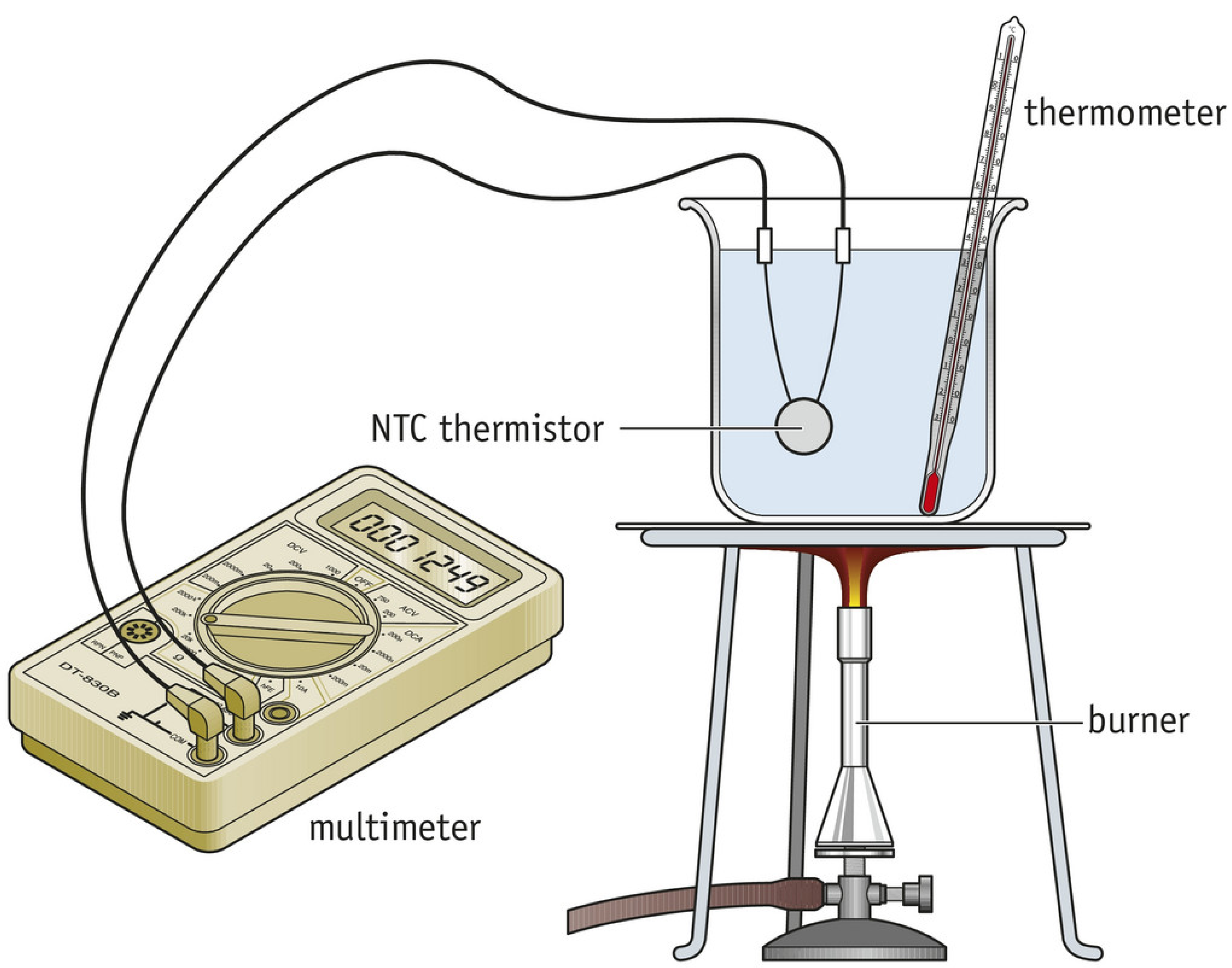
- **a** When Rick holds the LDR in bright sunlight, the current is 0.22 A.
  Calculate the resistance of the LDR.
- **b** The current is only 0.1 mA six hours later.
  Calculate the resistance of the LDR.
- **c** How can the resistance of the LDR have become so much higher in six hours?

***20** You need worksheet 6-3 for this exercise.
Joanne is doing the experiment that has been drawn in figure 20. She is using a multimeter to measure the resistance of the NTC thermistor. You can see her measurements in table 3.

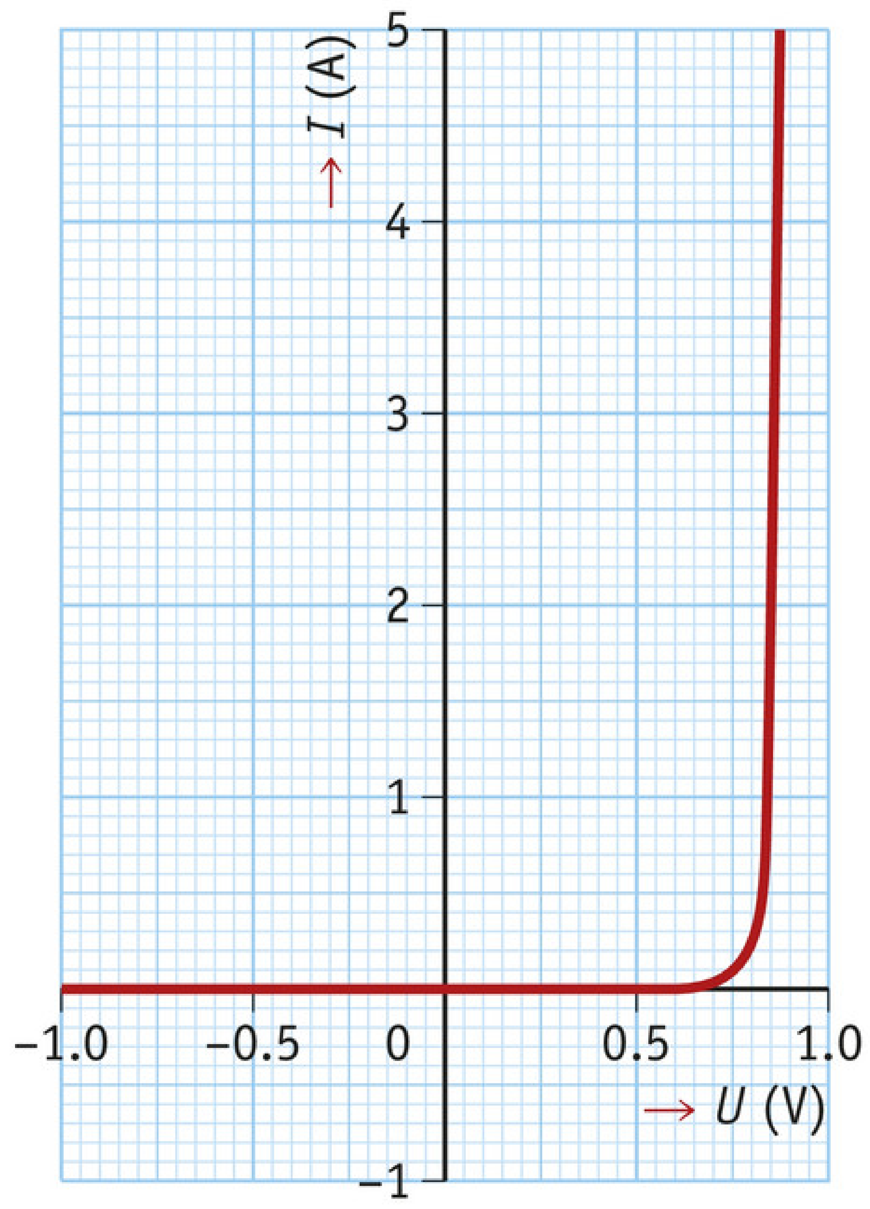
- **a** Draw a graph of Joanne's measurements on the worksheet.
- **b** Use this graph to read off how high the temperature is:
  - when the multimeter indicates 605 Ω.
  - when the multimeter indicates 79 Ω.
- **c** Explain why calculating the temperature above 1249 Ω or below 72 Ω does not give a result that you can be sure of.

▼ **table 3** Joanne's measurements

temperature (°C)	resistance (Ω)
20	1249
30	785
40	511
50	341
60	255
70	176
80	129
90	96
100	72



▶ **figure 20**
Joanne's experimental setup



▲ **figure 21**
the (I,U) diagram of a diode

***21** An electronic component that is widely used in circuits is the diode. Figure 21 shows you the (I,U) diagram of a diode.

a Each diode has a certain 'forward voltage'. What is meant by this voltage?
b Determine the forward voltage for this diode.
c What can you say about the resistance of a diode that is above and below the forward voltage?
d Explain how you can compare a diode to the valve of a bike tyre.

Plus The resistance of your body

***22** If you touch a copper wire that is at 230 V, you will get an electric shock.

a Calculate the approximate contact resistance:
- for a mild, harmless shock (I = 10 mA).
- for a serious, potentially dangerous shock (I = 100 mA).
- for a very serious, life-threatening shock (I = 1 A).

b Explain, using your answers to a, why there are strict safety rules for the electrical systems in a bathroom.

23 Search the Internet for information about lie detectors (figure 22).

a How does a lie detector measure the resistance of the skin?
b How does the skin resistance change if the test subject starts to sweat?
c Why is sweat a much better conductor than pure water?
d What else does a lie detector measure besides the skin resistance?
e Why does not everyone agree about the use of a lie detector?

Lie detector

The resistance of the skin depends on how damp the skin is. This property is used in a lie detector. This device is used to check if a suspect is lying during an interrogation. Psychologists believe that people sweat more when they are lying than when they are telling the truth. A rapid change in the suspect's skin resistance when answering a question shows that the suspect is lying. The method is mainly used in the United States and it is still rather contentious.

▲ **figure 22**
measurements with a lie detector

3 Working with resistors

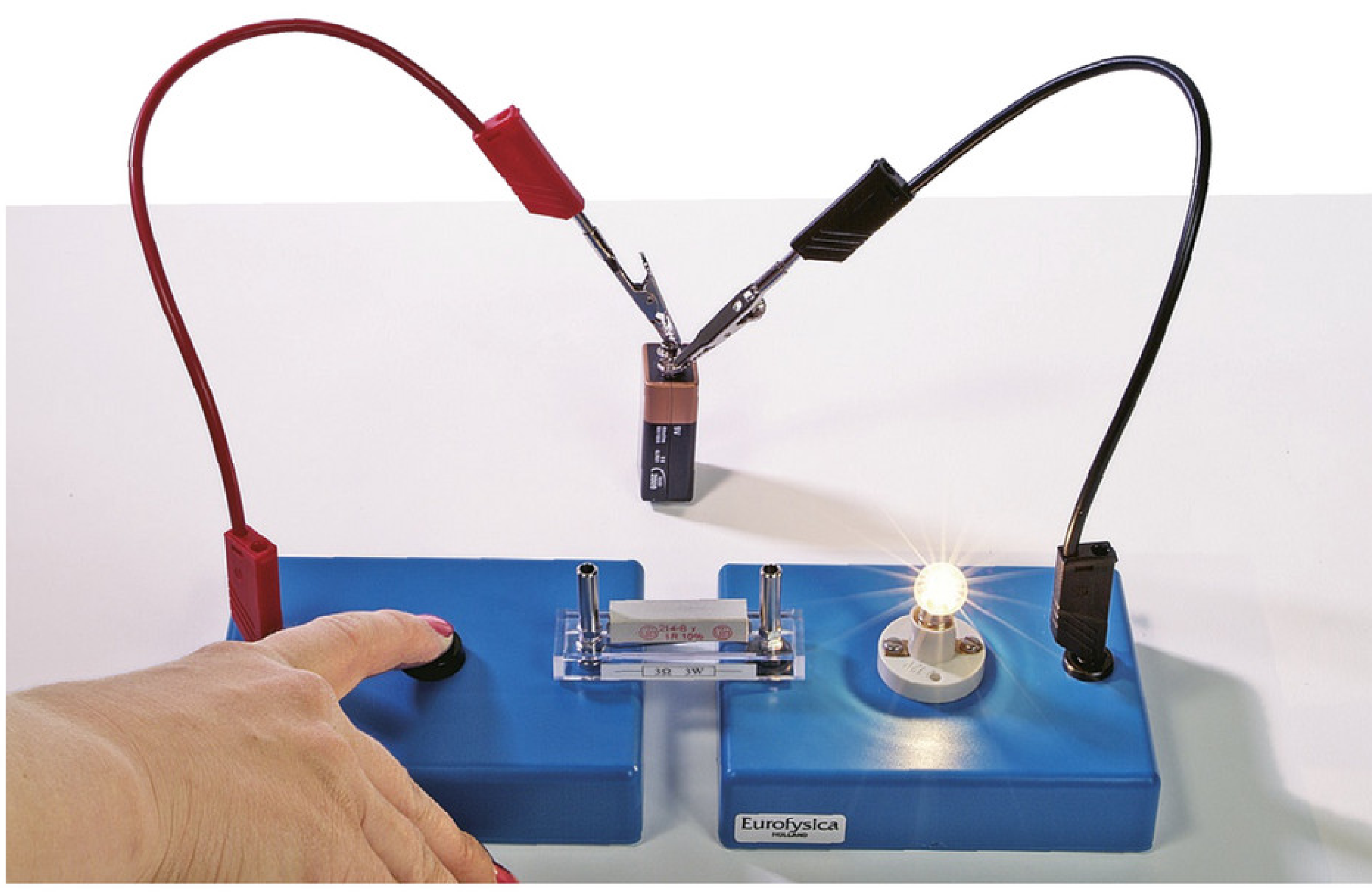
Computers and televisions have complex circuits with hundreds of components. The designer of such a circuit always looks carefully at the resistance of these components and adds resistors if necessary. Otherwise the current could be too large somewhere in the circuit and components may then break down because of overheating.

Increasing the resistance

The bulb in figure 23 is connected to a voltage of 6 V. This is the voltage for which this bulb has been designed. At this voltage, the current through the bulb has exactly the right value.

You cannot connect the bulb to a 9 V battery just like that. The resistance of the bulb is too low for that voltage. If you connect this bulb directly to a voltage of 9 V anyway, the current will become too high, the bulb burns out.

▲ **figure 23**
The bulb is lit at the correct voltage.



▲ **figure 24**
The resistor makes sure that the bulb does not burn out.

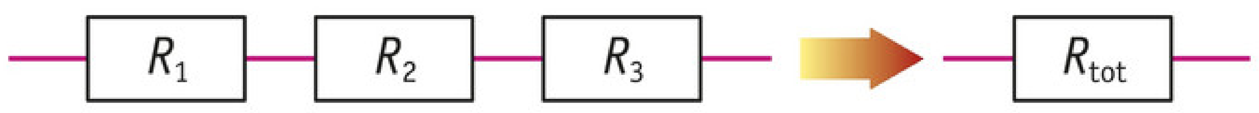
You might want to use a 9 V battery though, for example because you do not have another battery. You can still do that, but you have to increase the total resistance first. You then need a circuit component with the right resistance for the purpose. Such a component is called a **resistor**.

Once you have found the right resistor, you have to connect it in series with the bulb (figure 24). This will increase the total resistance of the circuit. This lets you reduce the current to a value where the bulb will not burn out.

Resistors in series Experiment 4

If you connect more and more resistors in series, the resistance of the whole circuit will get higher and higher. The current will decrease more and more if the voltage stays the same. You can calculate the total resistance R_{tot} by adding all the resistances (figure 25):

$$R_{tot} = R_1 + R_2 + R_3 + \ldots$$



▲ **figure 25**
Resistances connected in series can be added up.

If you replace all resistors with a single resistor with the value of R_{tot}, this will have no effect on the rest of the circuit. The total resistance is also called the **equivalent resistance**.

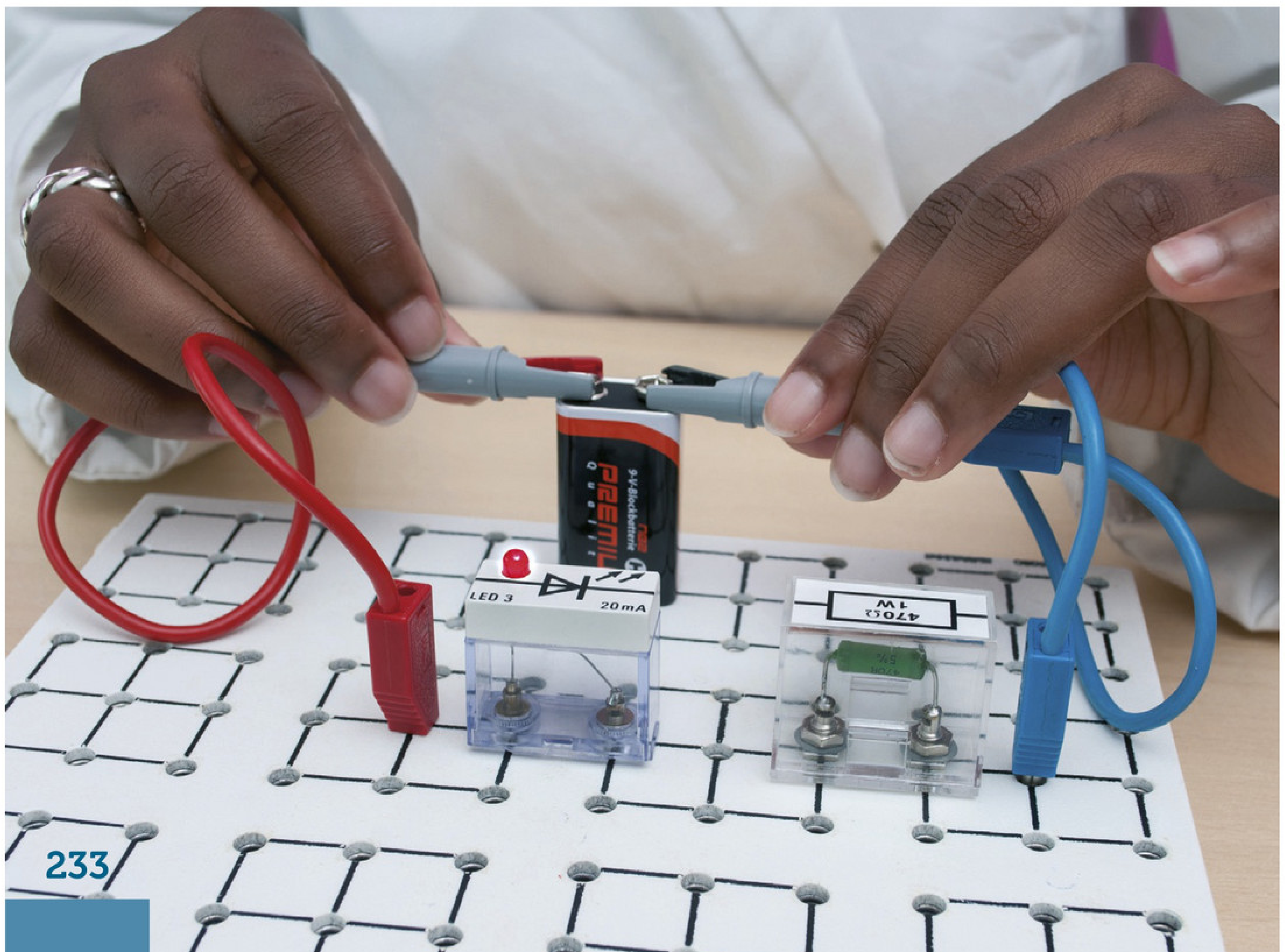
Current and voltage in a series circuit

The current I is equally high everywhere in a series circuit. There are no branches where the current has to split. However, in a series circuit voltage has to be split across the various circuit components. If you connect two bulbs of the same resistance in series and connect them to a battery of 9.0 V, each bulb will be lit at 4.5 V. Each bulb gets half the source voltage.

If the two bulbs have different resistances, the source voltage U_{tot} will not be divided exactly in two. Bulb 1 has then a voltage of $U_1 = I \cdot R_1$ and bulb 2 a voltage of $U_2 = I \cdot R_2$. When you add them up, U_1 and U_2 equal the source voltage: $U_{tot} = U_1 + U_2$. If multiple resistors are connected in series, the following applies:

$$U_{tot} = U_1 + U_2 + U_3 + \ldots$$

Resistors are often used to make sure that other circuit components work at the correct voltage. Figure 26 shows an example. Because the voltage of the battery is too high for the LED bulb, it is connected in series with a resistor. Only part of the voltage is then across the resistor. The rest of the voltage is exactly high enough to make sure the LED bulb will be lit properly.



▶ **figure 26**
An LED is connected in series with a ballast resistor.

Worked example 2
The LED bulb in figure 26 is lit just right when the voltage is 2.0 V. A current of 20 mA then flows through the bulb. The battery delivers a voltage of 9.0 V.
Calculate what the value of the resistor must be to make sure the bulb is lit at the right voltage.

data $U_1 = 2.0$ V
$U_{tot} = 9.0$ V
$I = 20$ mA $= 0.02$ A

requried $R_2 = ?$

working $U_{tot} = U_1 + U_2$
$9.0 = 2.0 + U_2$
$U_2 = 7.0$ V

$$R_2 = \frac{U_2}{I} = \frac{7.0}{0.020} = 3.5 \cdot 10^2\ \Omega$$

Resistors in parallel Experiment 5

If you connect more and more resistors in parallel, the total resistance of the circuit will not be higher – as in a series circuit – but lower. Because the number of branches increases, the current can flow more easily. If the voltage stays the same, the current will therefore keep increasing.

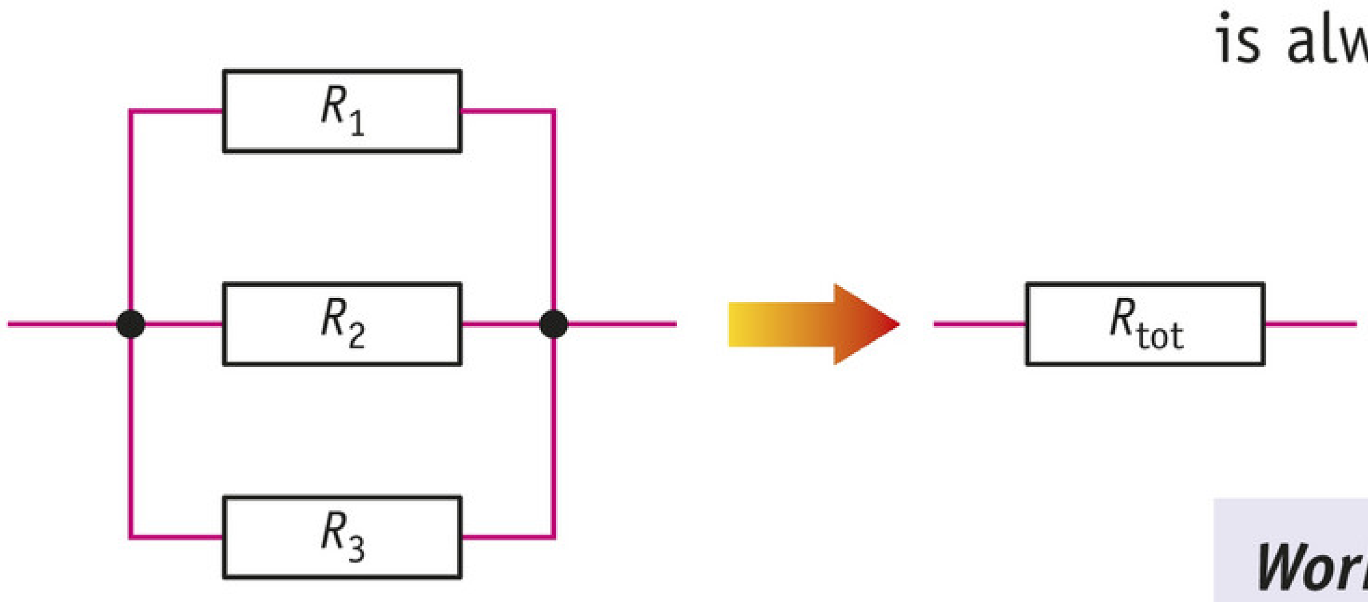
That is why you should not just keep connecting more and more circuit components in parallel. If you do the wires supplying the circuit would soon be overloaded. To prevent overloads, a domestic electricity supply is divided up into circuits, each circuit has a limited number of circuit components. This method is not only used for the domestic electricity supplies but also for the lighting installation at a big concert (figure 27).

▶ **figure 27**
A lighting rig is divided into circuits, just like a domestic electricity system.

You can calculate the total resistance R_{tot} of a parallel circuit using the formula (figure 28):

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

This formula shows that the total resistance (or the equivalent resistance) is always lower than any of the individual resistors (R_1, R_2 and so forth).



▲ figure 28
The total resistance will be lower when the resistors are connected in parallel.

Worked example 3
Esther connects a 55 Ω resistor in parallel with a 145 Ω resistor. Calculate the equivalent resistance.

data $R_1 = 55\ \Omega$
$R_2 = 145\ \Omega$

required $R_{tot} = \ldots$

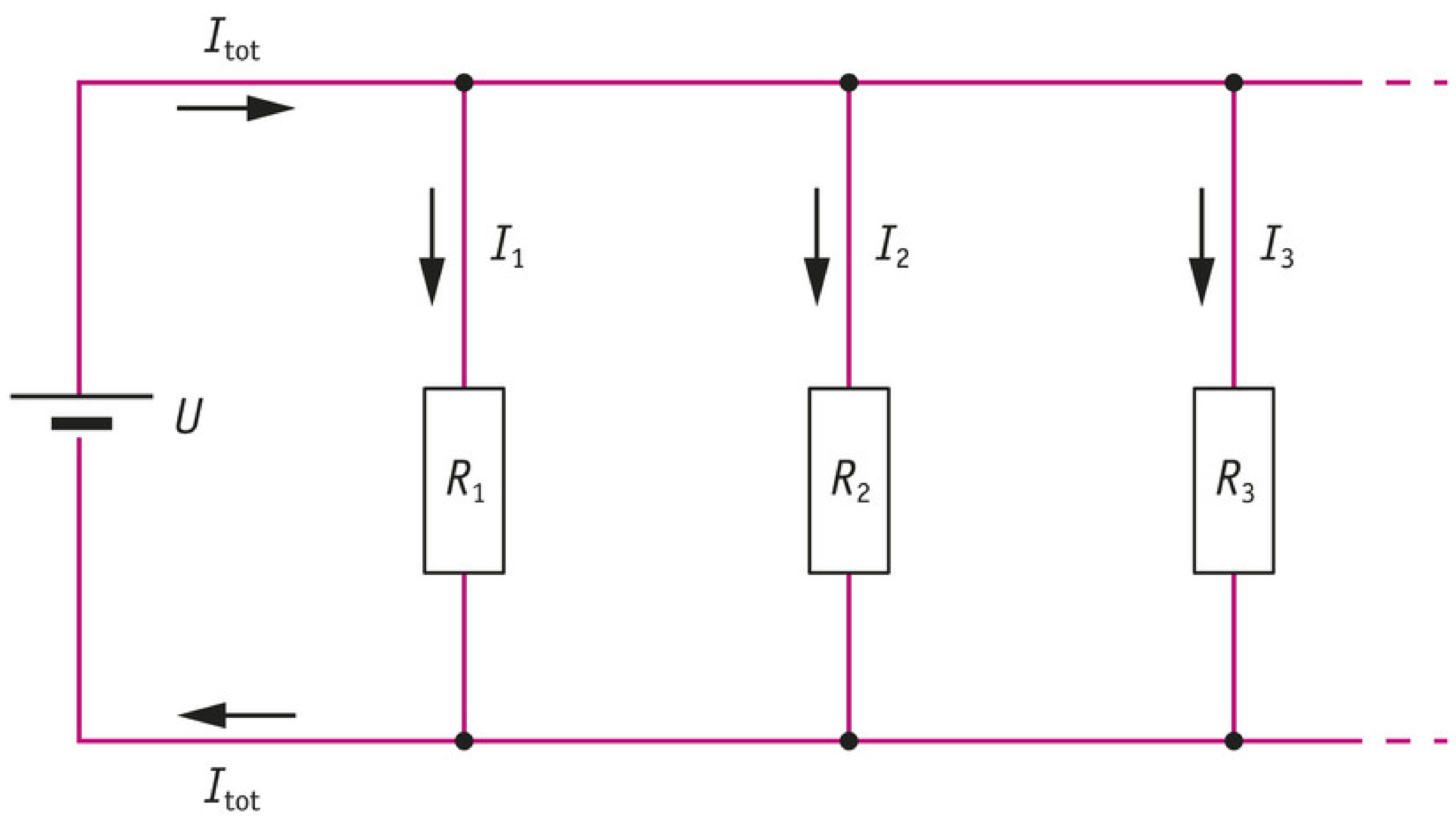
working $$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{55} + \frac{1}{145}$$

$R_{tot} \approx 40\ \Omega$

Current and voltage in a parallel circuit

Each circuit component in a parallel circuit is connected directly to the voltage source. Each component receives the full source voltage U. In a parallel circuit, the current splits between the various branches. Currents I_1, I_2, I_3 and so forth flow through each of the branches 1, 2, 3 etc. (figure 29). You can therefore calculate the total current using the formula:

▼ figure 29
The current splits in a parallel circuit.



$$I_{tot} = I_1 + I_2 + I_3 + \ldots$$

The total current is the current in the parts that have no branches, such as the power supply wires that all the current has to flow through. There is a risk of overload here if too many circuit components are connected at the same time.

Worked example 4
Calculate the total current in the circuit from worked example 3.

data $R_1 = 55\ \Omega$
$R_2 = 145\ \Omega$
$U = 9.0$ V

requried $I_{tot} = \ldots$

working $I_1 = \dfrac{U}{R_1} = \dfrac{9.0}{55} = 0.16363\ldots$ A

$I_2 = \dfrac{U}{R_2} = \dfrac{9.0}{145} = 0.06206..$ A

$I_{tot} = I_1 + I_2 = 0.16363\ldots + 0.06206\ldots$
$I_{tot} \approx 0.23$ A

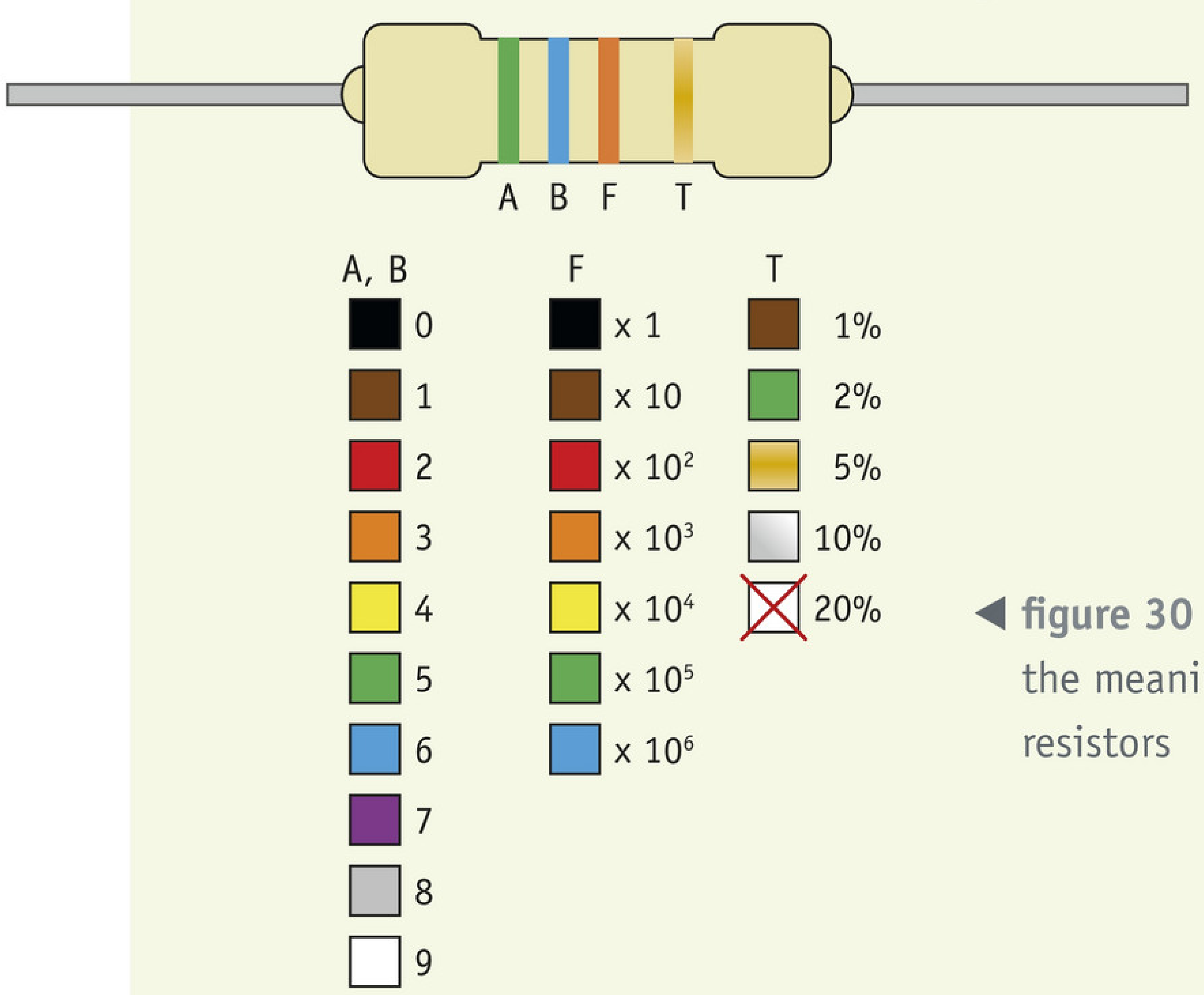
You get the same result if you divide the source voltage by the total resistance:

$I_{tot} = \dfrac{U}{R_{tot}} = \dfrac{9.0}{40} \approx 0.23$ A

Plus Resistor colour codes

Electronics uses lots of little resistors. You will find them in all kinds of circuits. These resistors are made by putting a thin layer of carbon on a glass rod. The thinner the layer of carbon is, the higher the resistance.

Each resistor has four or five coloured bands. You can find the meaning of the various colours for a resistor with four bands in figure 30. When reading the code, band T (the tolerance band) must be on the right-hand side of the resistor.



◀ **figure 30**
the meaning of the colour codes on electronic resistors

Worked example 5
Have a look at the resistor in figure 30.
Determine how large the resistance is.

band A is green → 5
band B is blue → 6
band F is orange → $\times 10^3$
band T is gold → ± 5%

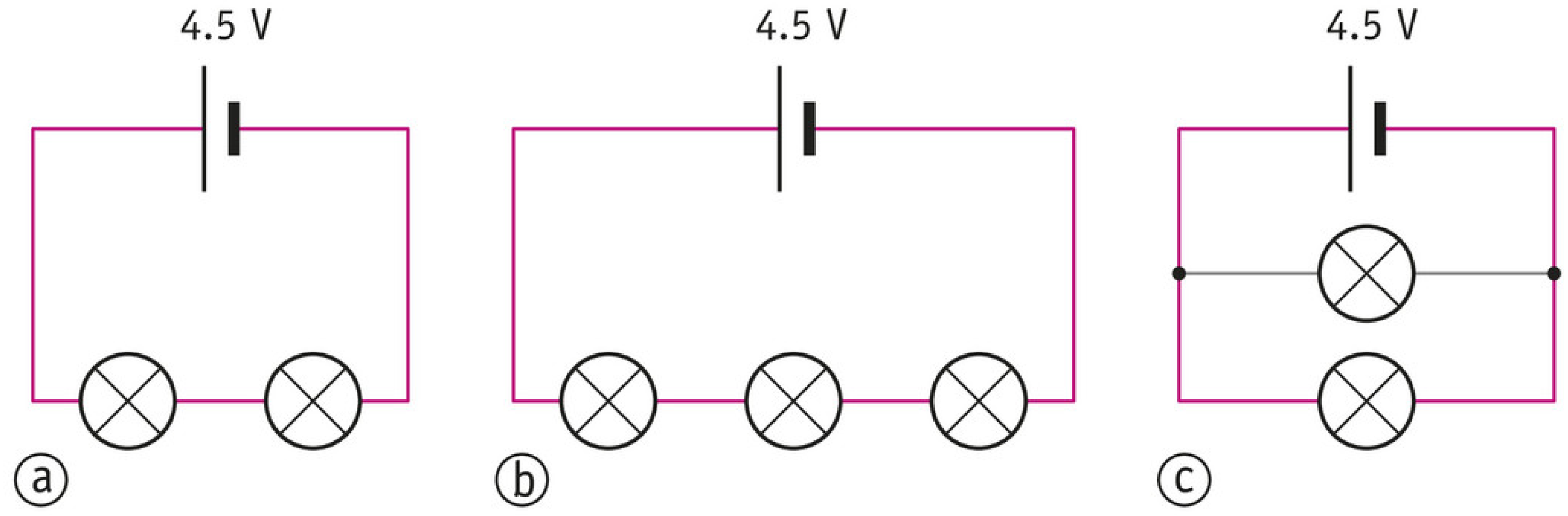
The resistance is therefore $56 \cdot 10^3\ \Omega = 56\ \text{k}\Omega$, with a maximum tolerance of 5%.

Exercises

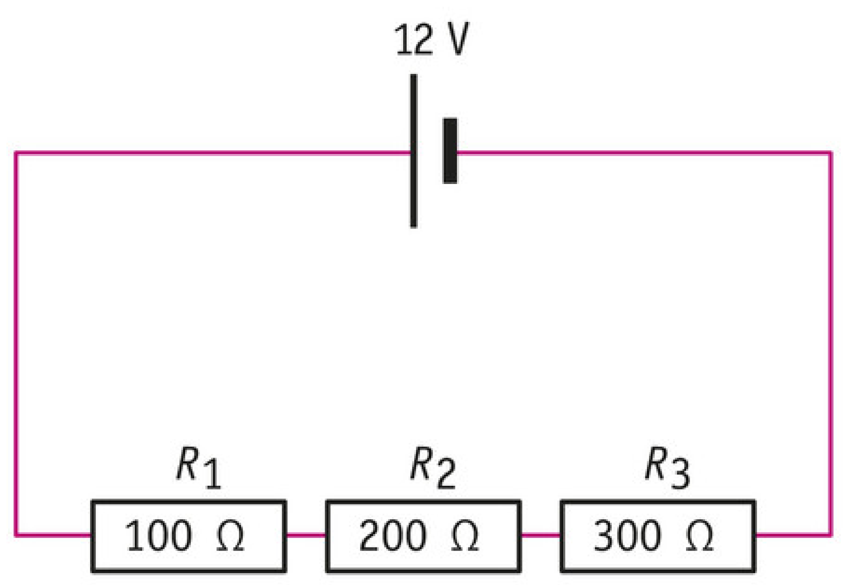
24 Answer the questions below.
- **a** How can you safely connect a bulb to a battery of 9 V if the bulb has been designed for a voltage of 6 V?
- **b** How does the total resistance of a series circuit change if you keep on increasing the number of resistors?
- **c** Why is the total resistance of a number of resistors also called the 'equivalent resistance'?
- **d** What formula can you use to calculate the equivalent resistance to three resistors that are connected in parallel?

25 In what kind of circuit:
- **a** is the current in the circuit equally high everywhere?
- **b** does the current split between the branches in the circuit?
- **c** does each circuit component receive the full voltage?
- **d** is the voltage split across the various circuit components?

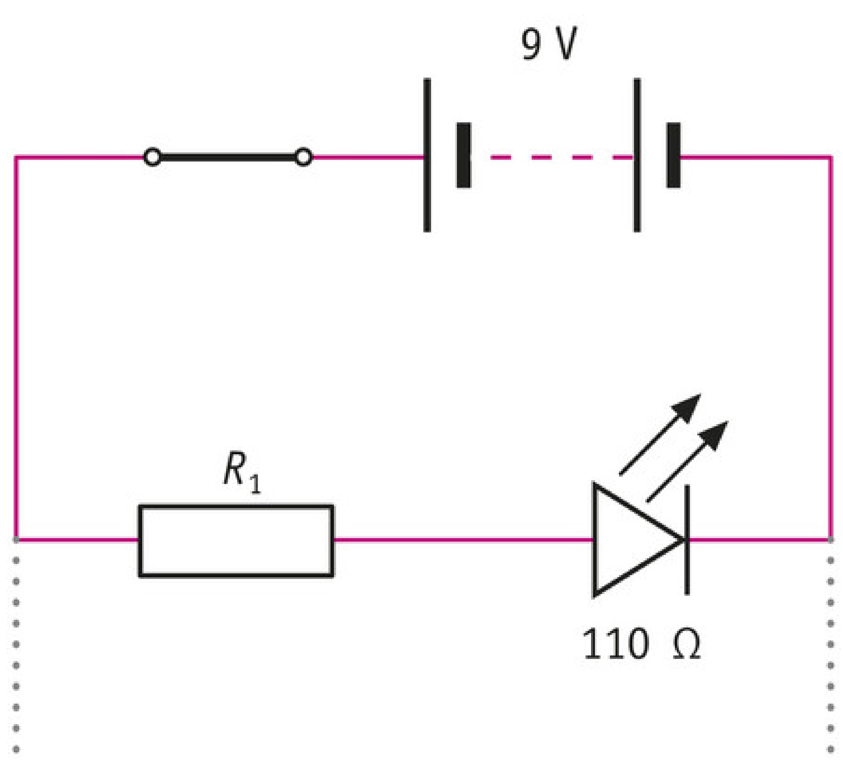
26 All bulbs in the circuits of figure 31 are the same.
- **a** In which circuit is the (total) resistance lowest?
- **b** In which circuit is the (total) current lowest?
- **c** In which circuit are the bulbs brightest?



▲ **figure 31**
three circuits with bulbs



▲ **figure 32**
a series circuit



▲ **figure 33**
an LED with a ballast resistor

27 Study the series circuit drawn in figure 32.
- **a** Calculate the total resistance.
- **b** Calculate the current.

28 A set of Christmas lights consists of 23 incandescent bulbs that are connected in series. Each bulb is marked 10 V/0.3 A. If all these lights are connected to 230 V, each bulb will be lit at the right voltage.
- **a** Calculate the resistance of one bulb.
- **b** Calculate the total resistance of all bulbs together, if they are lit in the normal way.
- **c** Use your answer to b to check if the current through this series circuit is really 0.3 A.

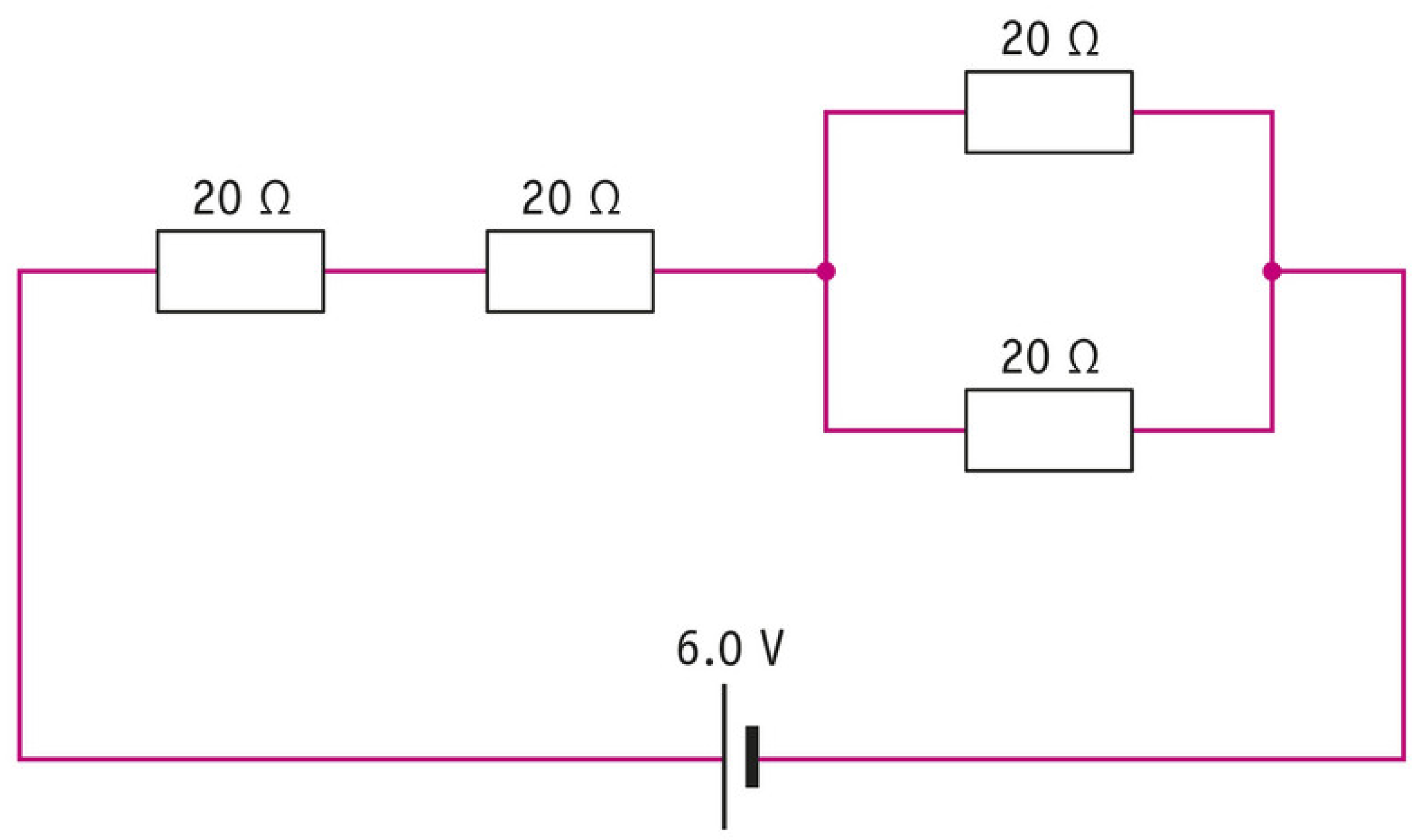
29 A wireless microphone works on a 9 V battery. If you switch the power on, an LED will light up (figure 33). The ballast resistor R_1 makes sure that the LED will not burn out. If the battery delivers 9 V, the current through the LED will be 18 mA.
- **a** Calculate the total resistance of the circuit.
- **b** Calculate the value of resistor R_1.

30 The bulbs of a bicycle lighting circuit are connected in parallel. The dynamo delivers a voltage of 6.0 V. The resistance of the front light is 20 Ω. The resistance of the rear light is 120 Ω.
- **a** Calculate the equivalent resistance of this parallel circuit.
- **b** Calculate the total current.

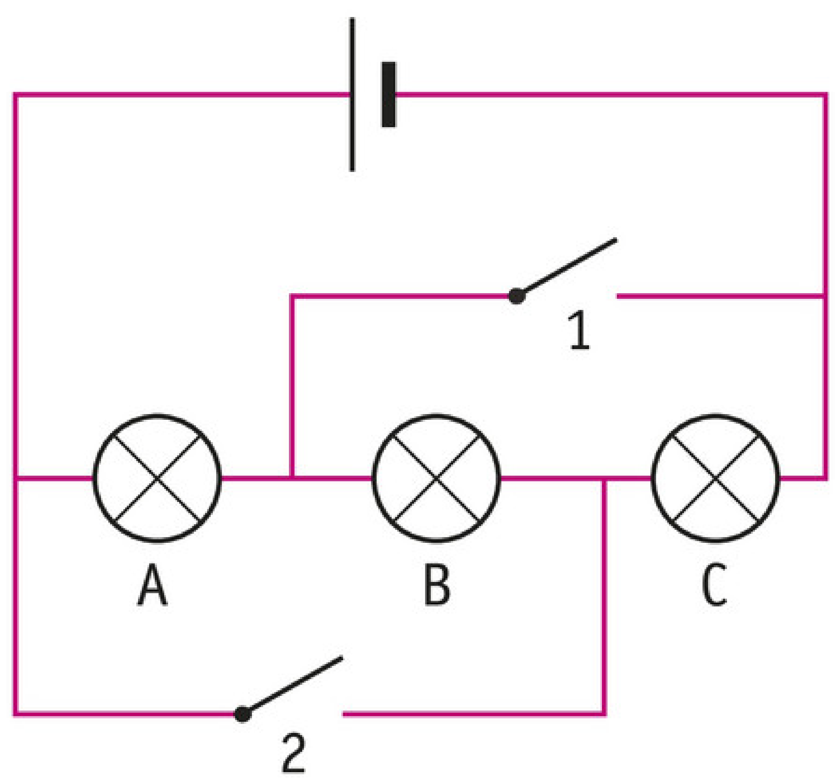
31 The hob of an electric stove has two heating elements, R_1 and R_2. R_1 has a resistance of 65 Ω, R_2 has a resistance of 35 Ω. The hob is connected to the mains (230 V).
Calculate the total current through the hob:
- **a** if R_1 and R_2 are connected in series.
- **b** if only R_1 is switched on.
- **c** if only R_2 is switched on.
- **d** if R_1 and R_2 are connected in parallel.

***32** Two resistors of 60 Ω and 40 Ω and a third unknown resistor R_3 are connected in parallel. The total resistance of the circuit is 15 Ω. Calculate the value of resistor R_3.

***33** Guy has four identical resistors of 20 Ω. He uses them to make a combination as shown in figure 34 and connects them to a voltage of 6.0 V.
- **a** Calculate the total current.
- **b** What are the highest and lowest total resistances that you can make with these four resistors?



▶ **figure 34**
Guy's resistor combination



▲ **figure 35**
a circuit with three identical bulbs

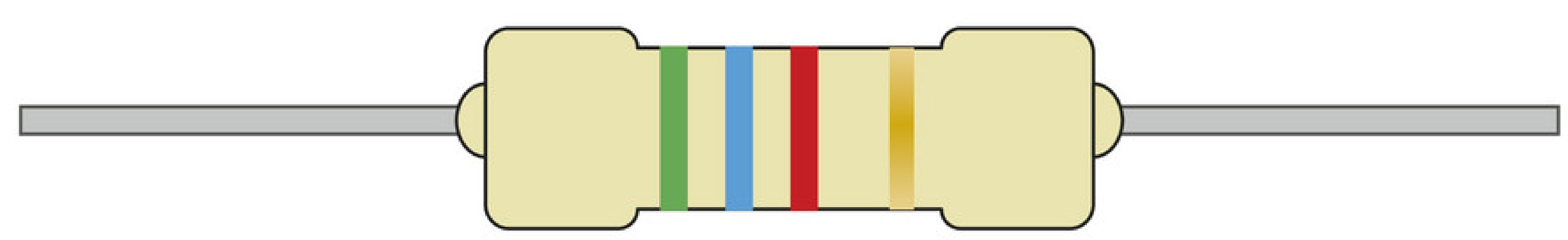
34 The circuit in figure 35 has three identical bulbs. If only switch 1 is closed, bulb A will be lit at the normal voltage.
Are there any other bulbs that are lit at the normal voltage when switch 2 is closed too?
A no
B yes, only bulb B
C yes, only bulb C
D yes, bulbs B and C
Source: IJSO

***35** Explain why (without using examples) the equivalent resistance of resistors that are connected in parallel is always lower than the smallest resistance that is used.

Plus Resistor colour codes

36 Figure 36 shows a resistor.
a Determine the value of the resistance.
b What is the maximum allowable tolerance percentage?
c Calculate the minimum and maximum values that the resistor could have.

▶ **figure 36**
a resistor



***37** Wanda and Tom want to build a circuit using an LED. The light of the LED is just right at a current of 19 mA. The resistance of the LED is then 80 Ω. Wanda and Tom also have:
– a 4.5 V battery;
– three resistors with a colour code orange-orange-brown-gold;
– one resistor with a colour code yellow-violet-black-gold.
a Determine the values of the available resistors, given the colour codes.
b Calculate what the resistance of the ballast resistor must be that Wanda and Tom need to use in the circuit.
c Show in a drawing how Wanda and Tom have to combine the resistors to make sure that the LED works perfectly.

4 Automatic circuits

Many cars have burglar alarms nowadays. If a car thief tries to force the doors, an alarm will sound and indicator lights will start flashing. The alarm may also activate an immobiliser system and block the fuel supply. This is all possible because of the circuits that detect the danger and respond to it.

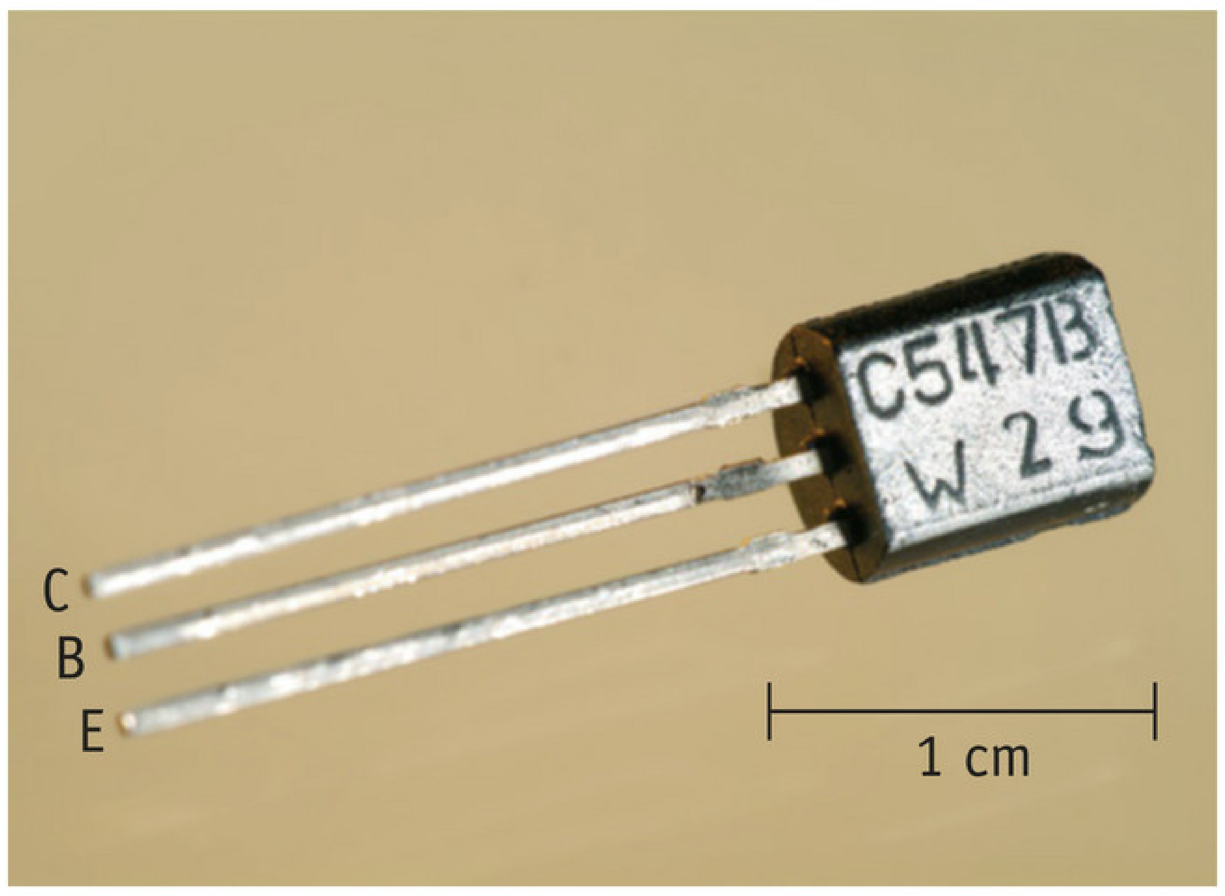
▲ **figure 37**
The circuit in a smoke detector responds to even a small amount of smoke.

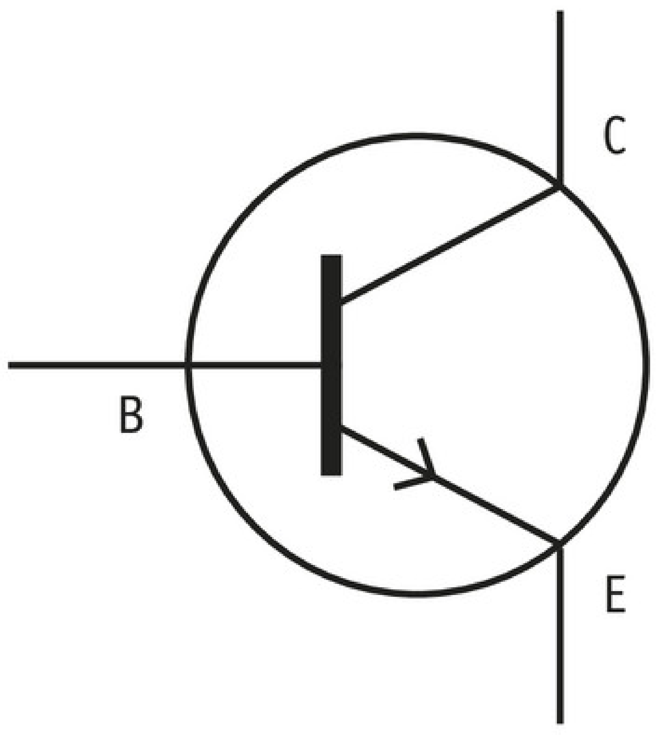
Sensor – switch – actuator

A lot of people have an outdoor light that turns on and off by itself. Such a light is operated by an automatic circuit that is made up of three parts: a **sensor**, a **switch** and an **actuator**.

Each component of the circuit has its own function:
- The sensor produces an electrical signal that gives information about the surroundings. This lets it 'tell' the circuit if something is changing in the surroundings.
- The switch responds to the information from the sensor. If the signal from the sensor requires a response, it switches the power on or off.
- The actuator does something that is useful or desirable at that moment: a light comes on, a siren starts sounding, a motor is started, etc. (figure 37).

Some outdoor lights have a sensor that responds to the amount of daylight. When it gets dark, the signal from the sensor changes. A switch in the lamp then turns the bulb on. There are also outdoor lamps that switch on when someone walks past. These lamps use an infrared detector as a sensor. This sensor responds to the infrared radiation given off by people and animals.



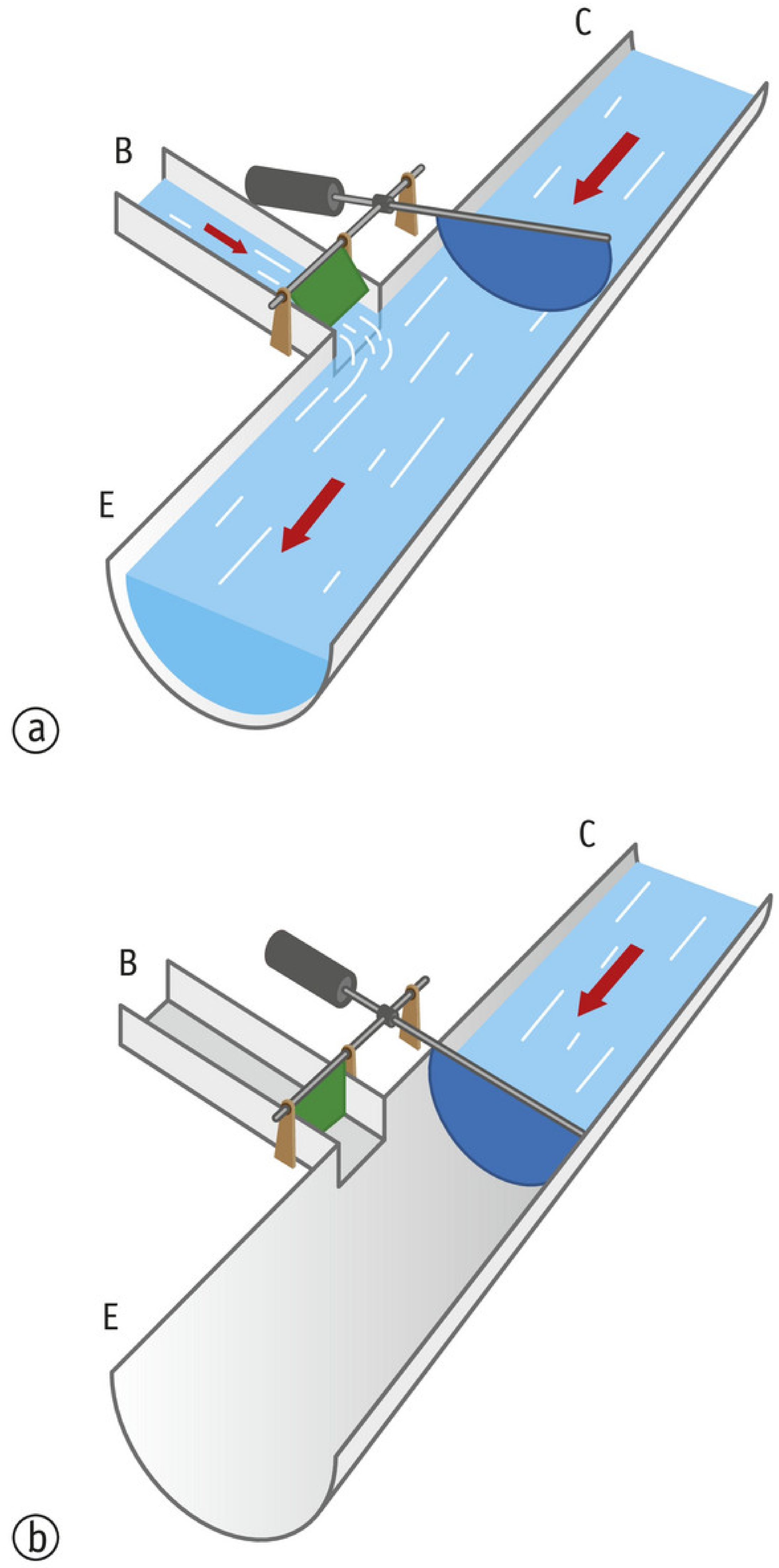


▲ **figure 38**
a transistor and the corresponding circuit symbol (below)

How a transistor works Experiment 6

In many automatic circuits, the actuators are switched on and off by a **transistor**. In that case, such a transistor acts as an automatic switch. As you can see in figure 38, a transistor has three connection points:
- the **collector** (C)
- the **base** (B)
- the **emitter** (E)

You can compare the way that a transistor works to the way a traffic barrier works. A barrier is raised or lowered to allow the traffic on a road to pass or stop. A transistor does the same with the current to a device. In the ON position, the transistor allows the current to pass, but in the OFF position it blocks the current.



▲ **figure 39**
a schematic representation of a transistor in the ON and OFF positions

- The transistor is turned to the ON position when a small current flows from the base (B) to the emitter (E). A much larger current can then flow from the collector (C) to the emitter (figure 39).
- The transistor is in the OFF position when no current (or very little current) is flowing from the base to the emitter. No current can then run from the collector to the emitter (figure 39b).

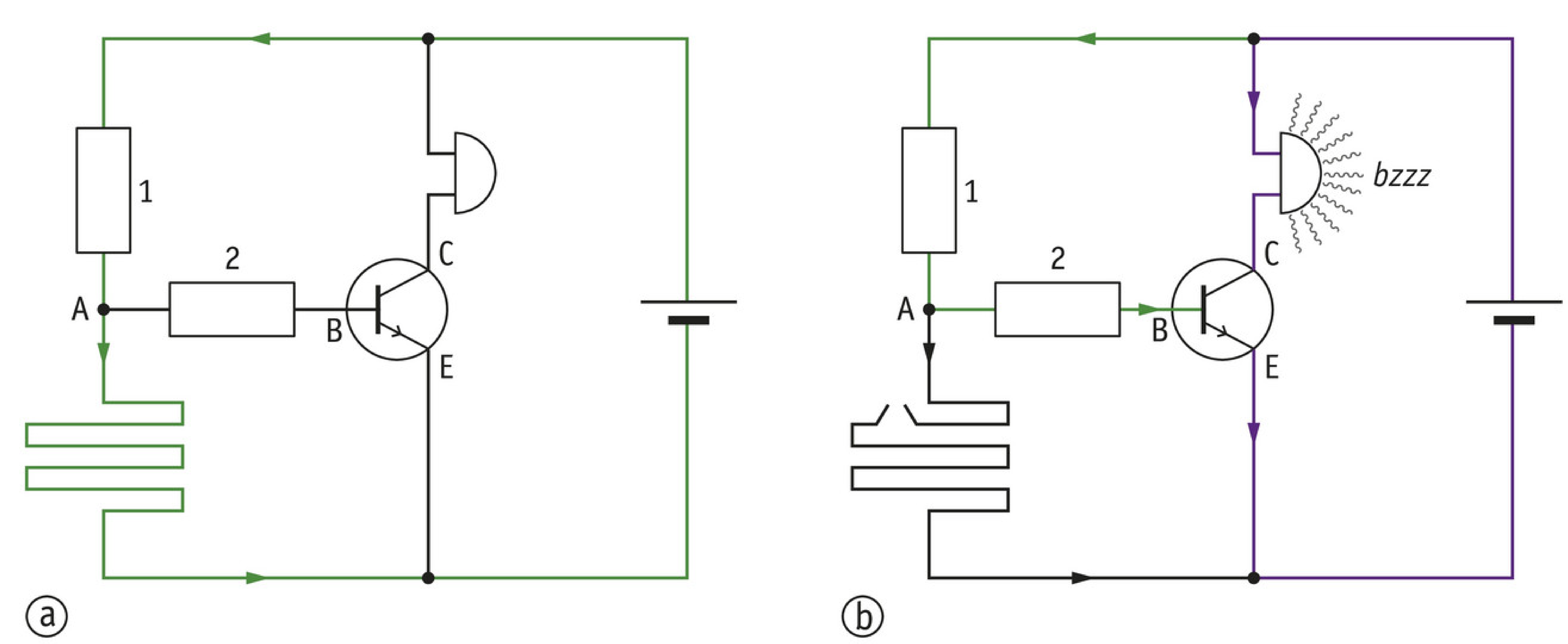
You therefore use a small 'switching current' (from B to E) to turn a much larger 'collector current' (from C to E) on and off. A transistor can easily get damaged if these currents become too large. That is why one or more resistors are often used in circuits with transistors. They work as current limiters.

A burglar alarm

Figure 40 shows a burglar alarm with a wire on a window. In this circuit, a wire on the window is used as a sensor. You can see that the current splits into two at A (figure 40a). The bulk of the current (more than 99.9%) goes through the wire on the window back to the battery. Very little current runs through the base (because it has a much higher resistance).

The size of the switching current through the base is the signal that the transistor responds to. As long as the wire remains undamaged, the switching current will be very small and the transistor stays in the OFF position. No current runs from C to E. The buzzer is off. Resistors 1 and 2 make sure that the currents that flow are kept as small as possible.

In figure 40b, someone has broken the window and the wire on the window is damaged. The current can only flow back to the battery via the base. The switching current from B to E will therefore be much larger. The transistor reacts to this signal by switching to the ON position. A large current can also flow from C to E now. The buzzer starts working.



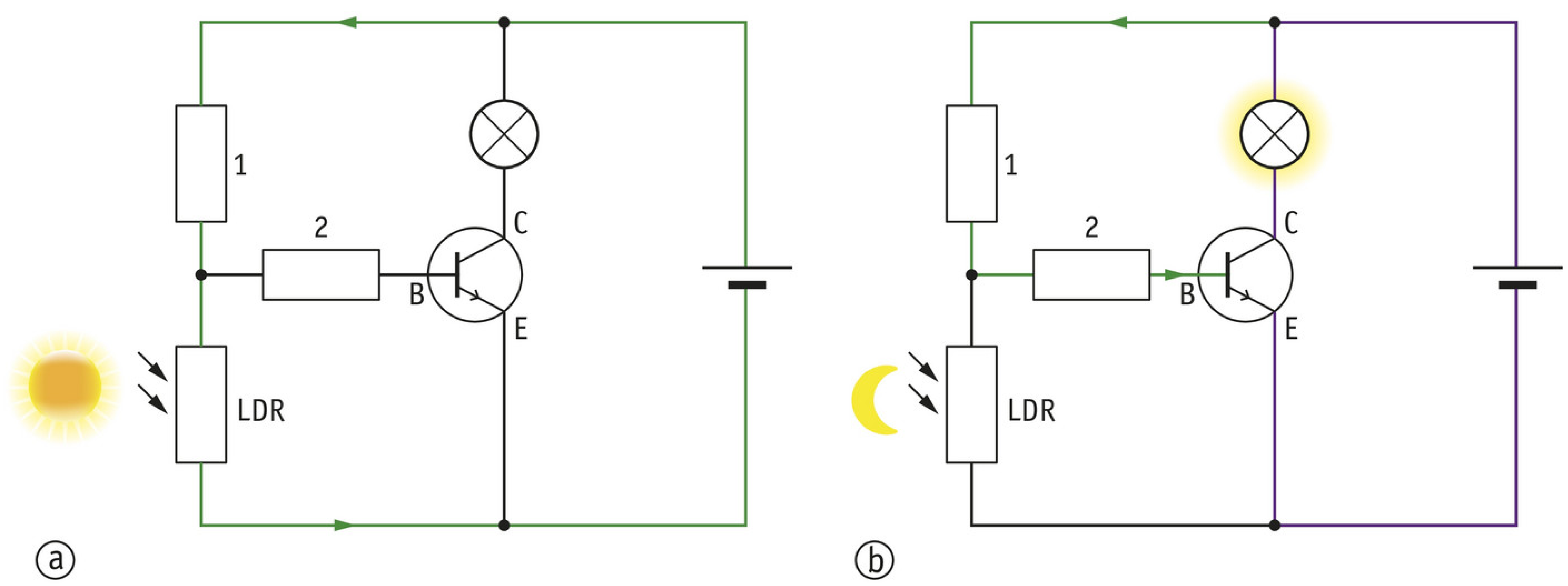
▶ **figure 40**
an alarm system with a transistor

An automatic streetlight

You can also use a transistor to build an automatic streetlight. You only have to change one thing in the circuit of figure 40a for this, the wire on the window has to be replaced by an LDR.

Figure 41a shows you the result. When it is light outside, the resistance of the LDR will be small. Almost all the current then flows through the LDR and not through the base. The transistor stays in the OFF position and the bulb is not lit.

When it is dark outside, the resistance of the LDR will increase. As a result, more and more current will flow through the base. More and more current will then flow through the bulb too. When it is completely dark, the bulb is fully lit (figure 41b).



▶ **figure 41**
an automatic streetlight

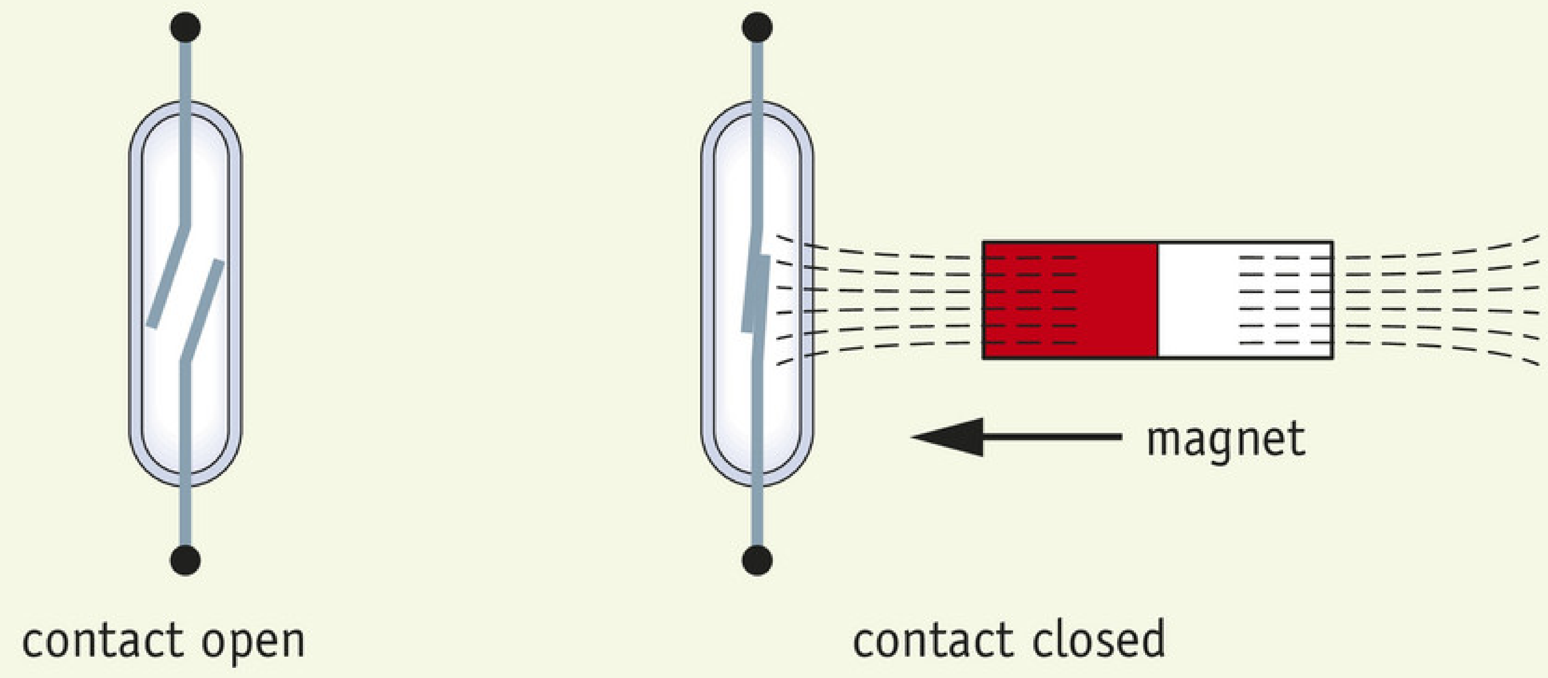
Plus A reed contact as a sensor

The burglar alarm in figure 42 uses a **reed contact** as a sensor. A reed contact is a glass tube containing two steel strips. If you hold a magnet close to the reed contact, the ends of the strips will touch each other (figure 43).

The reed contact is fixed to the window frame and a permanent magnet is fixed to the window. When the window is closed, the magnet makes sure that the reed contact is closed. An electrical current runs then through the contact. This current is a signal with the meaning 'Everything is OK here'.

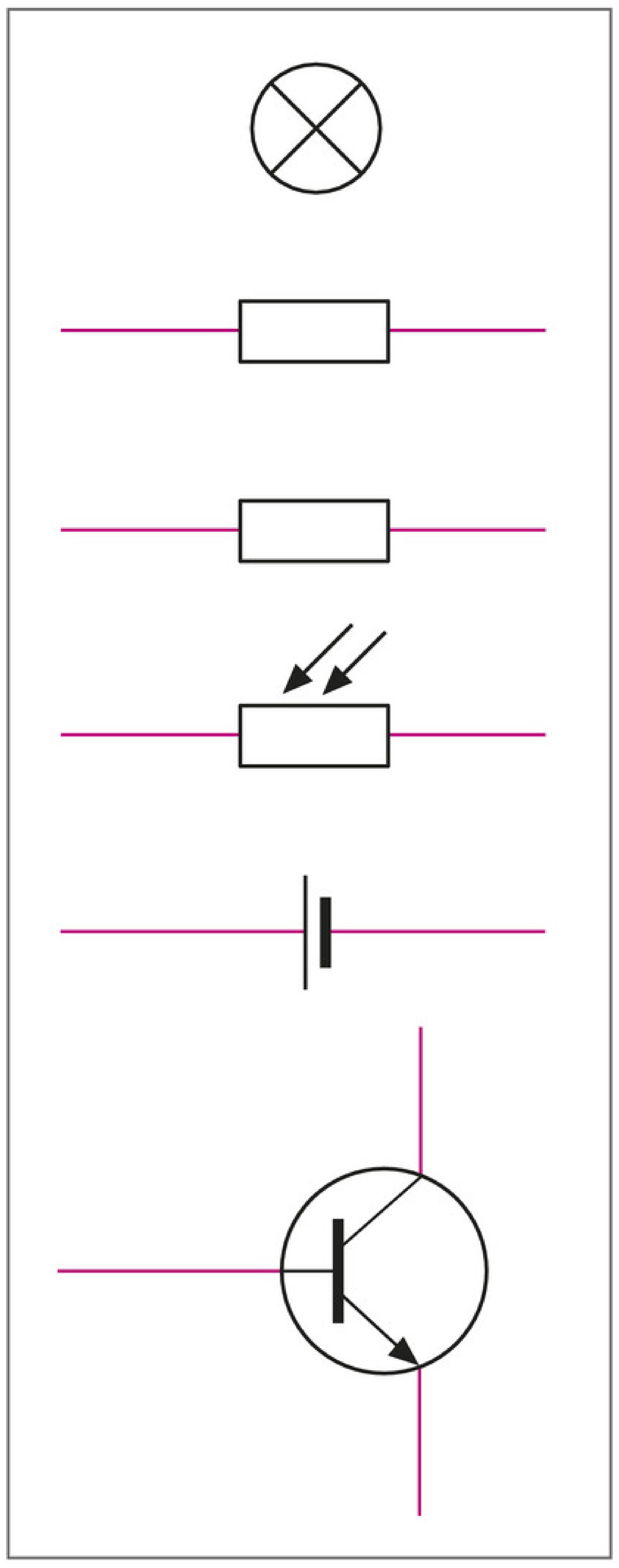
◀ **figure 42**
a burglar alarm with a reed contact

When the window with the burglar alarm is opened, the magnet will be moved away from the reed contact. The reed contact will not allow current to pass anymore. This power failure is a signal with the meaning 'Something is wrong, sound the alarm!'



▶ **figure 43**
A reed contact closes when a magnet is held close to it.

exercises



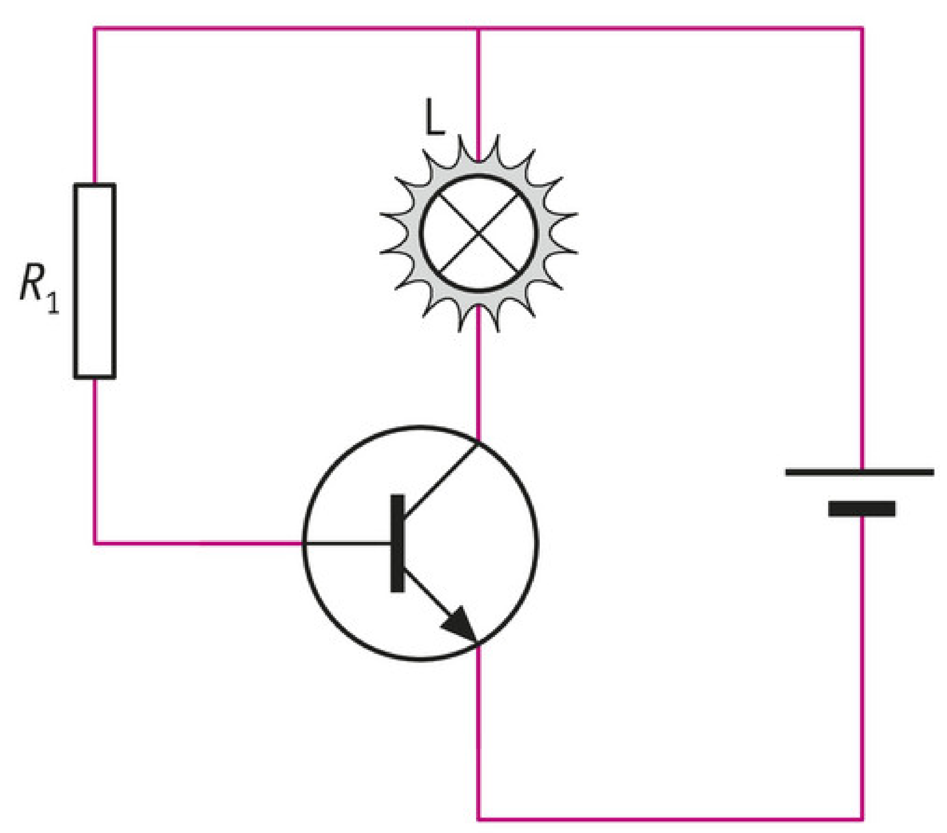
▲ **figure 44**
the components for an automatic streetlight

38 Answer the questions below.
- **a** What is the purpose of the transistor in a burglar alarm?
- **b** What are the names of the three connection points of a transistor?
- **c** When will a transistor allow the collector current to pass?
- **d** When will a transistor block the collector current?

39 You can use the six components in figure 44 and a few wires to build a model of an automatic streetlight.
Draw the circuit diagram for this circuit.

40 Six components that can be used in a circuit are listed below:
buzzer – electric motor – LDR – LED bulb – NTC thermistor – transistor.
- **a** Which components are sensors?
- **b** Which component is a switch?
- **c** Which components are actuators?

41 You can find various automatic circuits in a home.
Which automatic circuit:
- **a** switches off the voltage of a circuit, when there is a short circuit or overload somewhere in the house?
- **b** switches on the central heating, when the temperature in the living room has dropped below the set value?
- **c** warns the residents about a fire, when there is smoke somewhere in the house?
- **d** turns the lights on at night for a couple of hours to make it look as if the residents are at home?

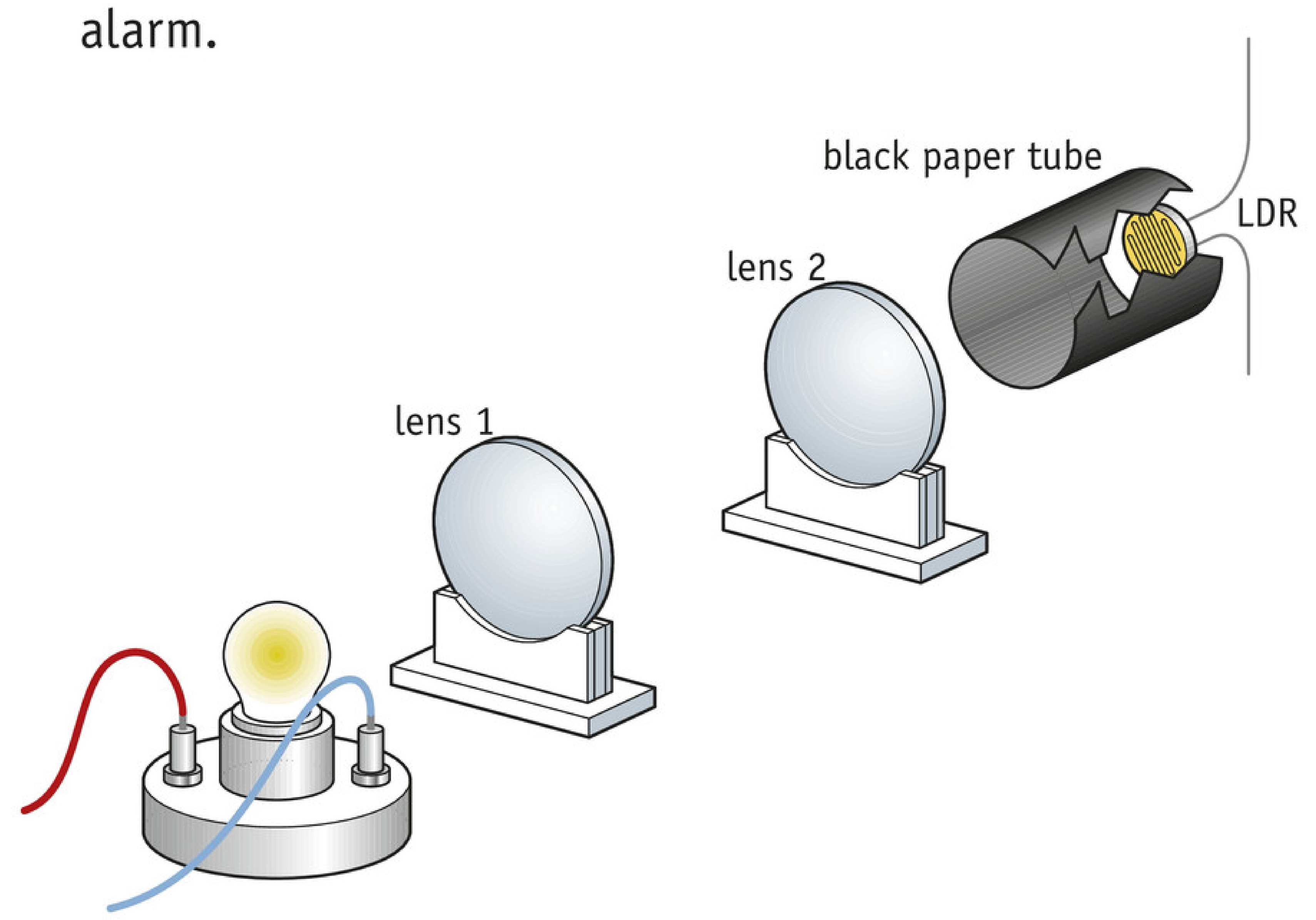


▲ **figure 45**
Philippa's circuit

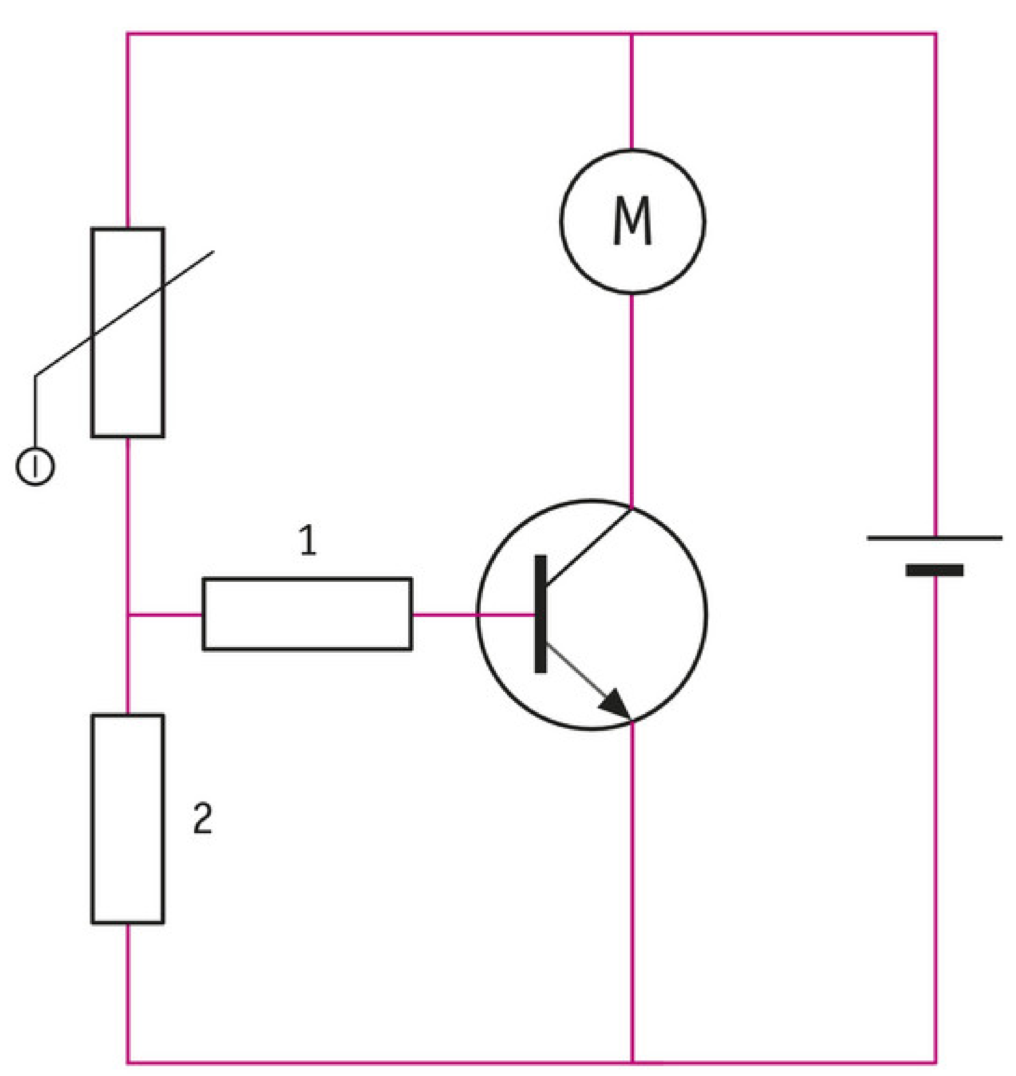
42 Philippa has made a test circuit with a transistor (figure 45).
a Copy the figure and put a B at the base, a C at the collector and an E at the emitter of the transistor.
b Which current is greater: the one through the bulb or the one through the resistor?
c Philippa replaces the normal resistor R_1 with an LDR. When she puts her hand across the LDR, the bulb goes out.
Explain why the bulb goes out. In your answer, explain what happens to the current through the base.

43 A certain type of burglar alarm uses a light gate to detect people. The light gate consists of a light source that produces a thin beam of light, plus a light sensor. If a burglar (or anyone else) breaks the beam, the sensor will detect it.
a Figure 46 shows a drawing of a light gate.
Explain:
- what lens 1 is used for.
- what lens 2 is used for.

b Make a simple burglar alarm that can sound a buzzer when the beam is broken. Draw the circuit diagram for the alarm.
c You can also construct this alarm using an infrared laser and an infrared sensor.
Explain what the advantage is of using infrared radiation for a burglar alarm.



▲ **figure 46**
a model of a light gate

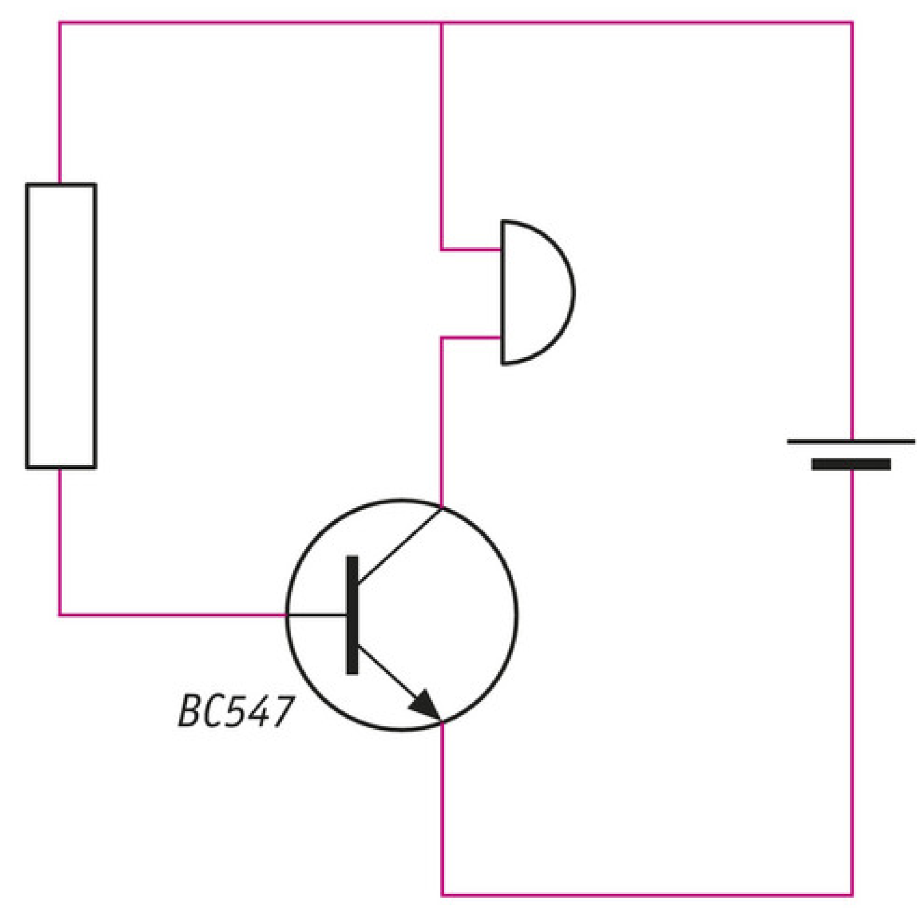


▲ **figure 47**
a fan that depends on the temperature

44 Computer chips can get very hot. That is why most computers have a fan that blows cool air across the chips. The circuit in figure 47 can automatically control the speed of the fan.
Explain:
a which circuit component in this circuit is acting as a sensor.
b how this sensor reacts when the temperature increases.
c how the switching current through the transistor then changes.
d why the fan starts to run faster.

45 Two resistors are used in the circuit in figure 47.
Explain:
- **a** which resistor is used to limit the current through the sensor.
- **b** what the other resistor is used for: which current does it limit?

***46** The circuit in figure 41 has one disadvantage: you cannot turn the lighting on when it is still light outside. You can solve this problem if you use a normal switch and two wires.
- **a** Explain whether you have to connect the transistor and the normal switch in series or in parallel for this.
- **b** Draw the circuit diagram for the modified circuit that also lets you turn on the lighting during the daytime.

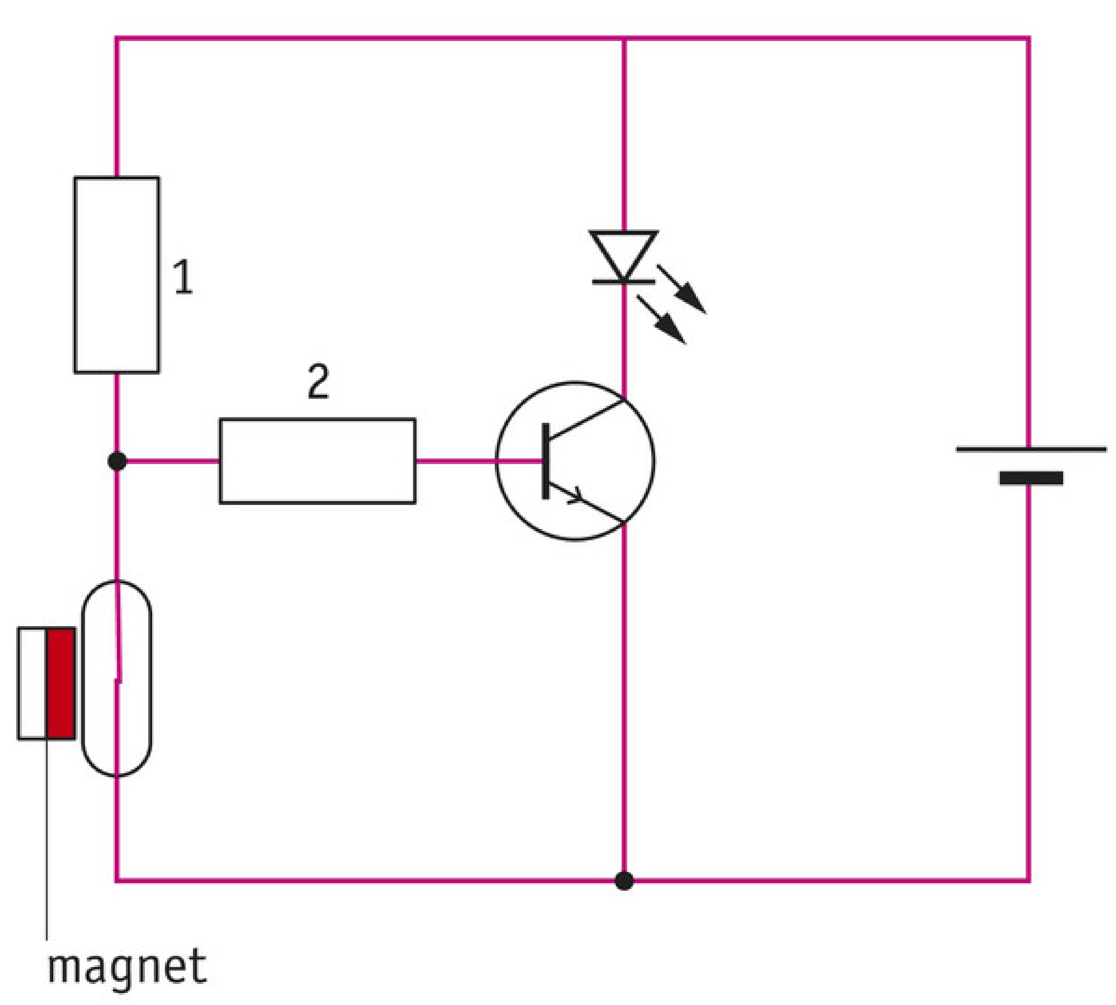


▲ **figure 48**
a circuit with a BC547 transistor

***47** The BC547 is a widely-used transistor. One use of this transistor is as a current amplifier. You can use a small base current (from B to E) to regulate a much larger collector current (from C to E).
The amplification factor of the BC547 is 250. This means that the collector current is 250 times as large as the base current.
- **a** What is the collector current, if the base current is 0.2 mA?
- **b** What is the base current, if the collector current is 80 mA?
- **c** Rose is making a circuit with a BC547 (figure 48). To make sure the buzzer works properly, the current through the buzzer has to be between 70 and 100 mA.
  What must the base current be as a minimum to make sure that the buzzer works properly?

Plus A reed contact as a sensor

***48** A window is secured by a door and window alarm with a reed contact and a small magnet. The reed contact is placed on the window frame and the small magnet on the window. Figure 49 shows you the circuit diagram.
- **a** In this circuit, what is:
  - the sensor?
  - the actuator?
- **b** How does the sensor react when someone opens the window?
- **c** Why is the actuator switched on then? Explain.



▲ **figure 49**
the circuit diagram for a window alarm

***49** Continuation of exercise 48.
Resistor 1 is an essential component of the circuit in figure 49.
- **a** Explain what the function of this resistor is.
- **b** A designer must choose the right value R_1 for resistor 1.
  Explain what goes wrong:
  - if R_1 is much too small.
  - if R_1 is much too large.

Experiments

Experiment 1 Attraction and repulsion 20 min

Introduction
You can charge objects by rubbing them with a cloth. There are various ways that you may notice that they are charged.

Aim
You are going to investigate the forces that charged objects have on other objects, and on each other.

Requirements
- 2 PVC tubes
- 2 Perspex rods
- a woollen cloth
- a silk cloth
- a turntable/holder
- a sheet of paper

Doing the experiment and writing it up
Experiment 1
- Tear the sheet of paper into little pieces.
- Rub a PVC tube firmly with the woollen cloth.
- Hold the tube close to the paper pieces.

1 Write down what you see.

Experiment 2
- Open a tap and adjust it so that it is giving a fine stream of water.
- Rub a PVC tube firmly with the woollen cloth.
- Hold the rod close to the fine stream of water.

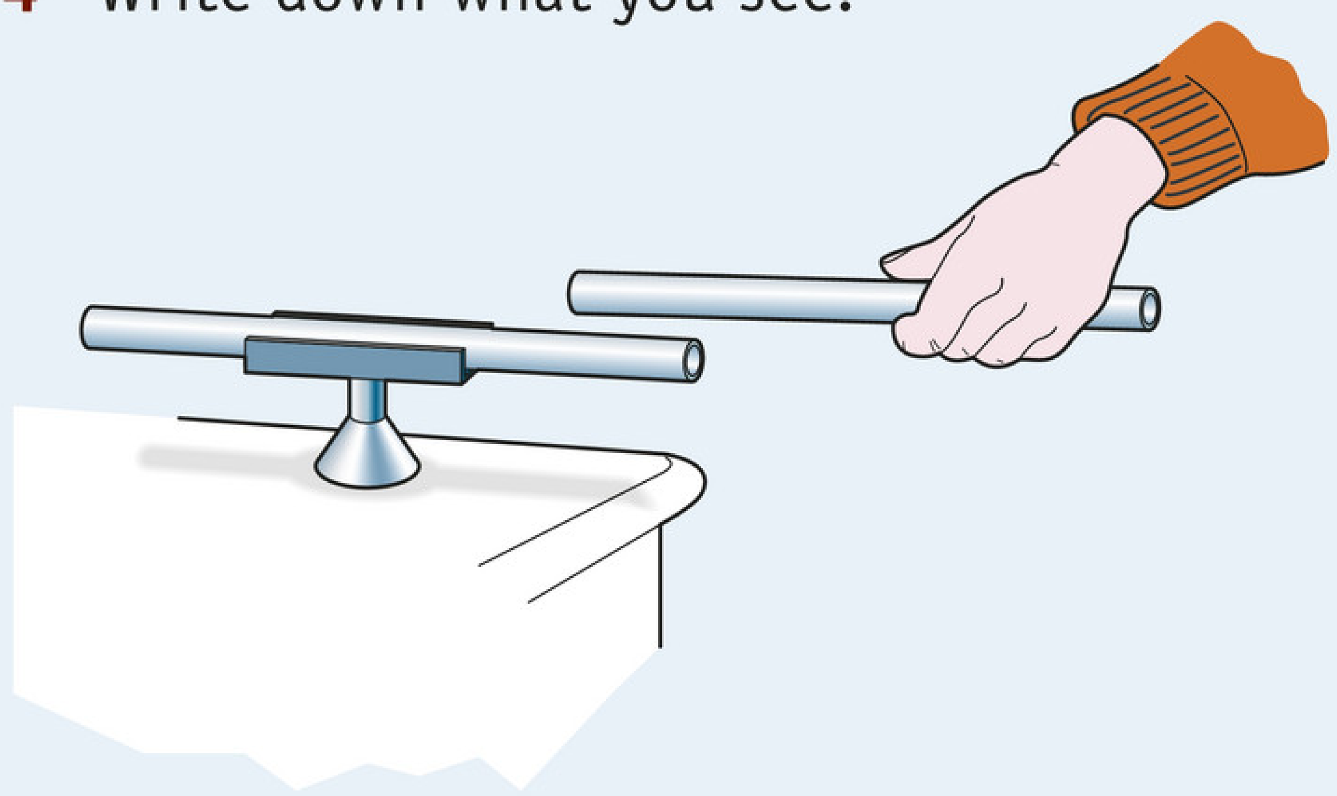
2 Write down what you see.

Experiment 3
- Rub a Perspex rod firmly with the silk cloth.
- Hold the rod close to the paper shreds.

3 Write down what you see.

Experiment 4
- Rub one of the PVC tubes with the woollen cloth. Then immediately put the pipe on the turntable.
- Rub the second PVC tube with the woollen cloth. Then hold it close to the first PVC tube (figure 50).

4 Write down what you see.



▲ **figure 50**
Attraction or repulsion?

Experiment 5
- Rub one of the PVC tubes with the woollen cloth. Then immediately put the pipe on the turntable.
- Rub a Perspex rod with the silk cloth. Then hold it close to the PVC tube.

5 Write down what you see.

Experiment 6
- Rub one of the Perspex rods with the silk cloth. Then immediately put the rod on the turntable.
- Rub the other Perspex rod with the silk cloth. After that, hold it close to the first Perspex rod.

6 Write down what you see.

Conclusions

7 What forces (attraction or repulsion) are there:
  - **a** between a charged and a neutral object?
  - **b** between two charged PVC tubes?
  - **c** between two charged Perspex rods?
  - **d** between a charged PVC tube and a charged Perspex rod?

8 How can you investigate if a randomly charged object has the same charge as a PVC tube?

Experiment 2 The (I,U) diagram of a constantan wire 40 min

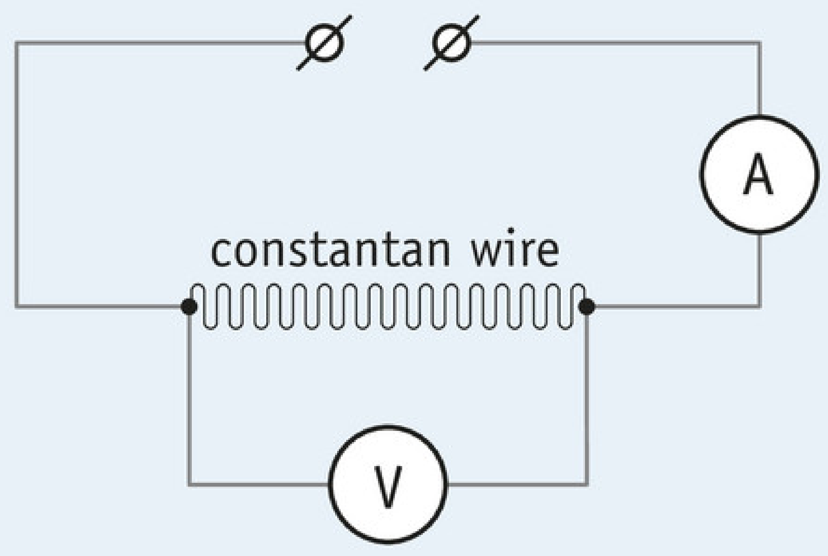
Introduction
When you change the voltage in a circuit, the current changes too. You can make measurements to find out how exactly the current changes. You increase the voltage step by step, check how large the current has become every time.

Aim
In this experiment you are going to do such an experiment with a constantan wire. The question you are studying is:
What is the relationship between the current and the voltage of a constantan wire?

Requirements
- power supply box
- 5 wires
- ammeter or multimeter
- voltmeter or multimeter
- constantan wire
- worksheet 6-4

Doing the experiment and writing it up
Measuring
- See 'Skills 4' at the back of the book. Make the circuit shown in figure 51.

If you need more practice, go to the V-trainer.



◀ **figure 51**
the circuit for experiment 2

- Set the voltage to 0 V before you switch on the supply.
- Increase the voltage in steps of 0.5 V and measure the corresponding current through the wire. Keep going until the voltage is 3 V.

1 Copy table 4. Make a note of your measurement data at the correct place in the table.

▼ **table 4** the measurement results for experiment 2

voltage (V)	current (A)	resistance (Ω)
0		
0.5		
1.0		
1.5		
and so forth		

Writing up

2 Take worksheet 6-4. Use the measurement results to make an (I,U) diagram.
3 What can you say about the relationship between the voltage across the wire and the current through the wire?
4 Calculate the resistance of the wire for each measurement. Write down the result in the third column of the table.
5 What do you notice when you compare the calculated resistance values against each other?
6 Could you have drawn the conclusion from question 4 from the diagram as well? Explain your answer.

Experiment 3 The (I,U) diagram of an incandescent bulb 30 min

Introduction
When you change the voltage in a circuit, the current changes too. The current in a constantan wire is proportional to the voltage. The two variables move up and down together. But is the result of this experiment the same for other types of wires?

Aim
In this experiment you are going to do the same investigation as in experiment 2, but now with a filament. The question you are studying is:
What is the relationship between the current and the voltage of a filament?

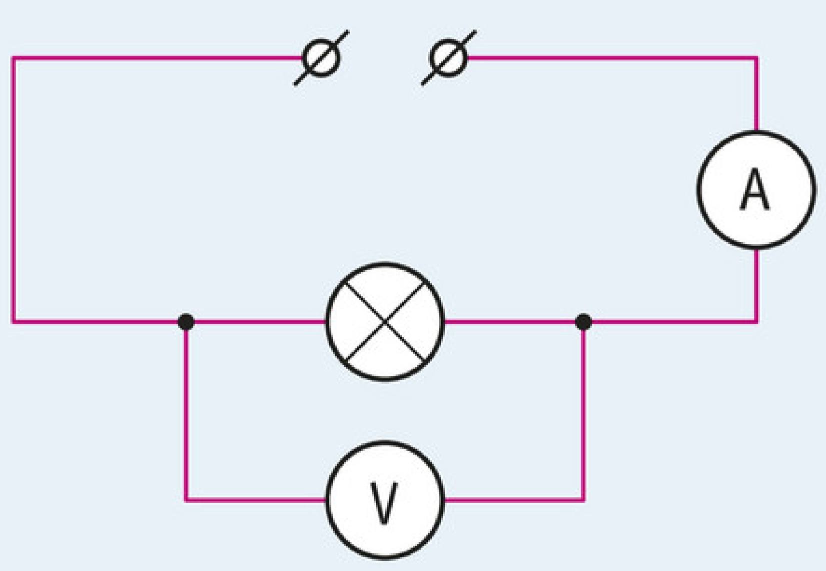
Requirements

- power supply box
- 5 wires
- ammeter or multimeter
- voltmeter or multimeter
- bulb
- fitting
- worksheet 6-5

Doing the experiment and writing it up

Measuring

– Make the circuit shown in figure 52.
– Set the voltage to 0 V before you switch on the supply.
– Increase the voltage in steps of 1 V and measure the corresponding current through the bulb. Keep going until the voltage is 6 V.



▲ **figure 52**
the circuit for experiment 3

1 Copy table 5. Write down your measurement data at the correct place in the table.

▼ **table 5** the measured results for experiment 3

voltage (V)	current (A)	resistance (Ω)
0		
1.0		
2.0		
3.0		
and so forth		

Writing up

2 Take worksheet 6-5. Use your measurement result to make an (I,U) diagram.
3 What can you say about the relationship between the voltage across the wire and the current through the wire?
4 Calculate the resistance of the incandescent bulb for each measurement. Write the result down in the third column of the table.
5 What do you notice when you compare the calculated resistance values against each other?
6 What is the value of the resistance of the bulb at a voltage of 0 V?
7 What could explain the change in the resistance? How can you test if this explanation is correct?

Experiment 4 The equivalent resistance in a series circuit 20 min

Introduction

Resistors are often connected in series. The following applies to the total resistance R_{tot} of such a circuit:
$R_{tot} = R_1 + R_2 + \ldots$

Aim

You are going to check the formula $R_{tot} = R_1 + R_2 + \ldots$ in a series circuit consisting of two resistors.

Requirements

- power supply box
- 6 wires
- voltmeter
- ammeter
- 2 resistors

Doing the experiment and writing it up

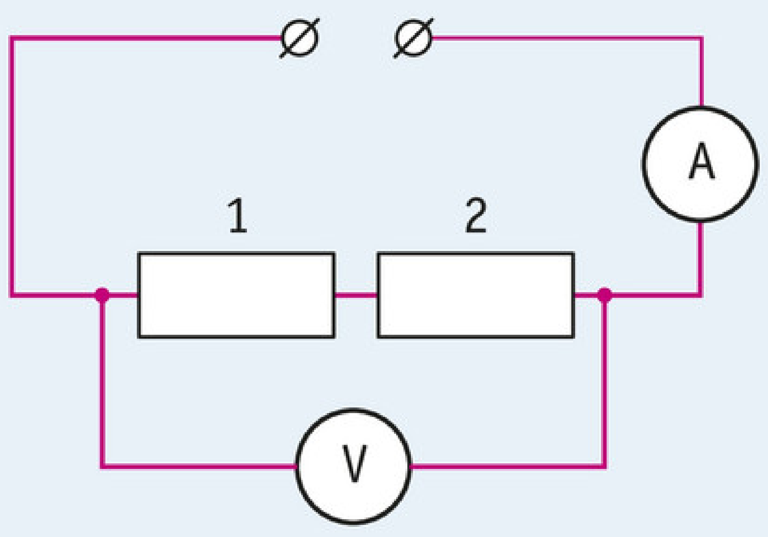
Measuring

– Determine the value of resistor 1.
– Determine the value of resistor 2.

1 Write down your measurements and calculations.

– Make the circuit shown in figure 53.
– Measure the (total) voltage and the current.

▶ **figure 53**
the circuit diagram for experiment 4



2 Write down your measurement results.

Writing up

3 Calculate the total resistance using the formula:

$$R_{tot} = \frac{U_{tot}}{I}$$

4 Calculate the total resistance using the formula:
$R_{tot} = R_1 + R_2$

5 Compare the answers to questions 3 and 4.
What conclusion can you draw?

Experiment 5 The equivalent resistance in a parallel circuit 20 min

Introduction

In experiment 4, you calculated the equivalent resistance of two resistors that were connected in series. In this experiment, you are going to work with the same resistors, but now you connect them in parallel.

Aim

You are going to check the formula

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

in a parallel circuit consisting of two resistors.

Requirements

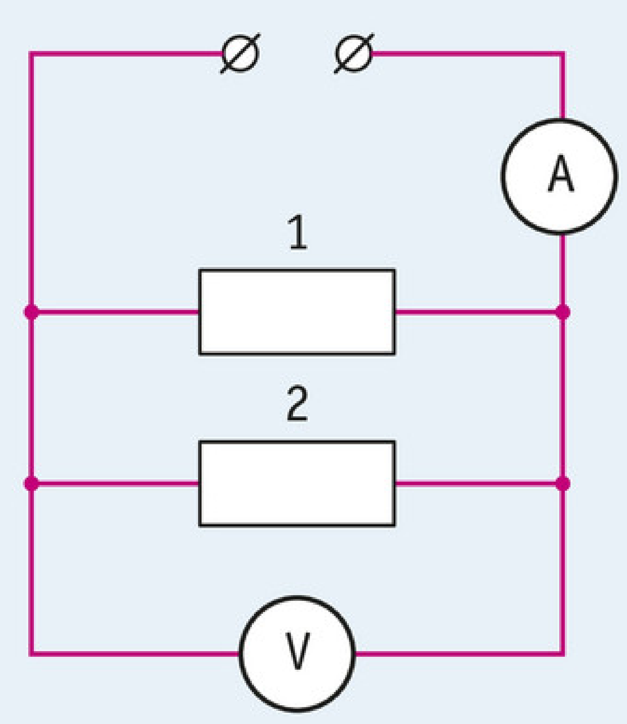
- power supply box
- 6 wires
- voltmeter
- ammeter
- 2 resistors

Doing the experiment and writing it up

Measuring

– Make the circuit shown in figure 54.
– Measure the voltage and the (total) current.

1 Write down the results of your measurements.



◀ **figure 54** the circuit for experiment 5

Writing up

2 Calculate the total resistance with the formula:

$$R_{tot} = \frac{U}{I_{tot}}$$

3 Calculate the total resistance using the formula:

$$\frac{1}{R_{tot}} = \frac{1}{R_1} + \frac{1}{R_2}$$

4 Compare the answers to questions 2 and 3.
What conclusion can you draw?

5 According to the theory, the total resistance in a parallel circuit is lower than both R_1 and R_2.
What about this parallel circuit?

Experiment 6 Switching with a transistor 45 min

Introduction

A transistor is an automatic switch that is used in many electrical circuits. It has three connection points: the base (B), the collector (C) and the emitter (E). You can make the transistor act as a switch using the small current that runs through the base.

Aim

This experiment shows you how a transistor works. By letting a small current run through the base, you can switch on a much larger current.

Requirements

- battery or power supply box
- transistor
- bulb
- 5 electronics resistors
- wires

Doing the experiment and writing it up

Before you start
Note! Transistors are easily damaged if the current is too high.

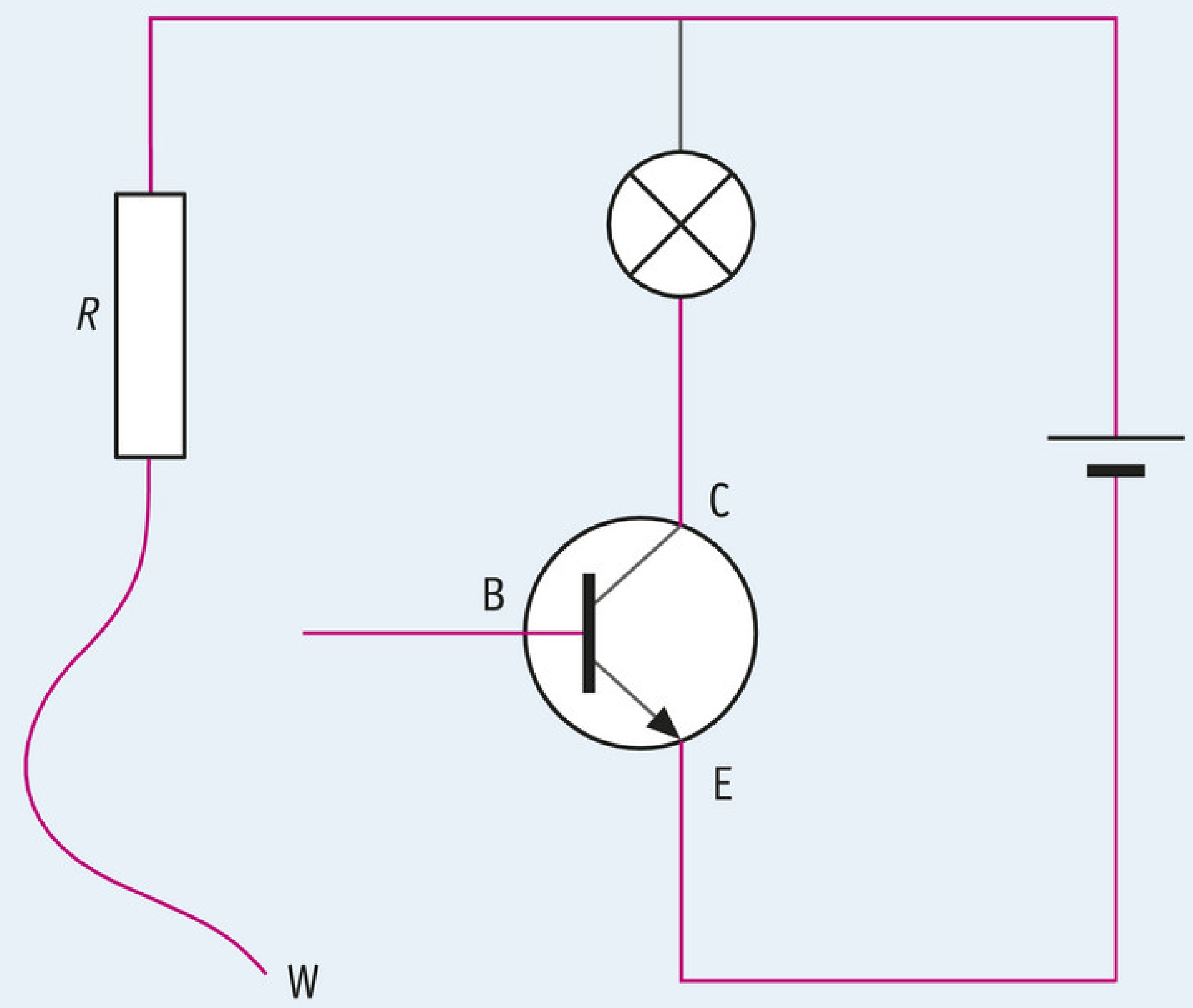
- Look at the colour codes on the five resistors.
- Determine the value of each resistor. See figure 30 on page 236.

1 Copy table 6 and write down the values of the resistors in the right place.

▼ **table 6** How bright is the bulb?

number	resistance (Ω)	the lamp is lit
1		brightly
2		
3		
4		
5		

- Construct the circuit shown in figure 55. For *R*, use the resistor with the lowest value.
- Your teacher will tell you what voltage you have to connect the circuit to.



▲ **figure 55**
the circuit for experiment 6

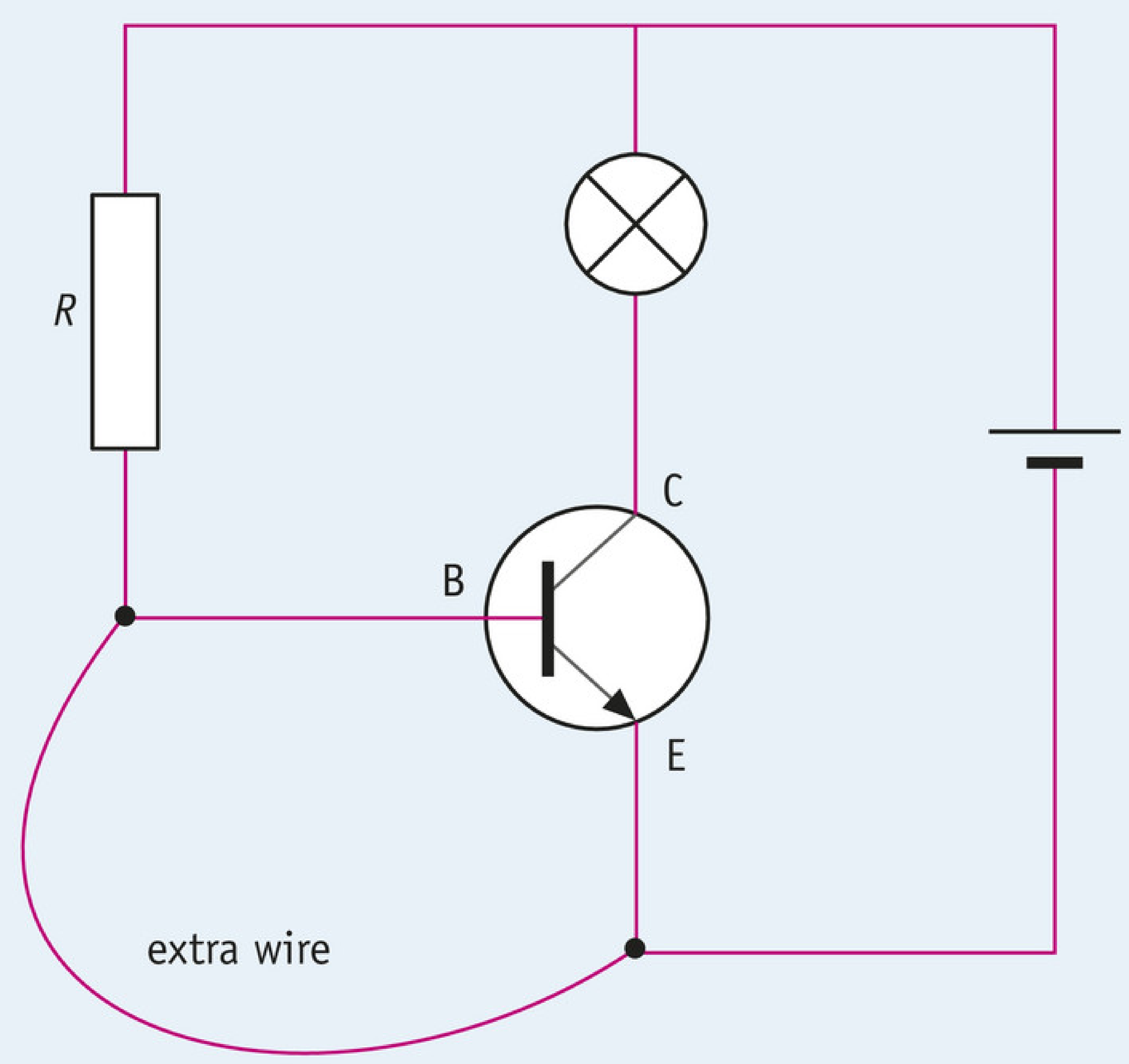
2 What happens if you touch the base with wire W?
3 What happens if you then remove the wire from the base?

- Connect wire W to the base. After that, test all the resistors one by one (in the place of *R*).

4 At the correct place in the table, write down how the bulb is lit: brightly, normally, dimly or not at all (hardly at all).

- Now add an extra wire to your circuit as shown in figure 56. You can use this wire to short-circuit the base of the transistor.

5 Why is the bulb not lit anymore? Explain.



▶ **figure 56**
What is the effect of the extra wire?

Experiment 7 Producing a design – anti-burglar lighting 45 min

Introduction
Imagine that there has been a break-in at the canteen of the sports club. To make sure this will not happen anymore, the manager wants to have a lamp lit in the canteen at night. "Lighting discourages burglars," he says. The lamp must come on automatically when it gets dark outside and go out when it gets light outside in the morning. The manager also wants to be able to switch the lamp on and off with a switch during the daytime. It is your job to think up a workable solution for this.

Aim
In this experiment, you will be thinking up and testing a circuit for the anti-burglar lighting in the canteen. Your circuit must meet the following requirements:

Design requirements
- The circuit switches the bulb on when it gets dark outside and switches the bulb off when it gets light again.
- The bulb is lit when it is starting to get dark outside but is not entirely dark yet.
- The bulb can be switched on during the daytime with a normal switch even if the Sun is shining.

Requirements
For this experiment, you have to think up for yourself what equipment you will need.

Doing the experiment and writing it up
– Think how you can carry out the exercise. What kind of circuit are you going to make? How should you choose the values of the resistors in your circuit? How are you going to test whether the circuit is working correctly? How can you make sure that no components will be damaged during the test?

1 Make a work plan for this experiment.

– The work plans will be discussed with the rest of the class at the next lesson. If necessary, you can make improvements to your own work plan after that.
– Build the circuit and test it out.

2 Make a test report that includes:
a a circuit that meets all the design requirements;
b the test you have carried out and the corresponding results;
c any changes that you made to your circuit.

Test Yourself

You can also do questions 1 to 16 on the computer.

1 Josh is doing a number of experiments with static electricity. A positively charged object A attracts a second object B in one of the experiments.
You can conclude from this that object B:
A is positively charged.
B is negatively charged.
C is neutral.
D is positively charged or neutral.
E is negatively charged or neutral.

2 When Tom goes to open a door, a spark jumps across between his finger and the doorknob.
a What particles are jumping between his finger and the doorknob?
b What charge do these particles have?

3 Sabrina rubs a Perspex rod with a silk cloth and after that, she puts the rod in a holder on a turntable. She then rubs a second Perspex rod with the same silk cloth and holds it next to the first rod.
What does Sabrina see?
A The first rod rotates away from the second rod.
B The first rod rotates towards the second rod.
C A spark jumps between the two rods.
D Nothing at all.

4 Marlene gets a static charge during a demonstration. It makes her hair stand on end.
Select the correct options.
The individual hairs *repel each other* / *attract each other*, because they all have *the same* / *a different* charge.

5 You can buy energy-saving bulbs for a pocket torch in a web shop. The description says:

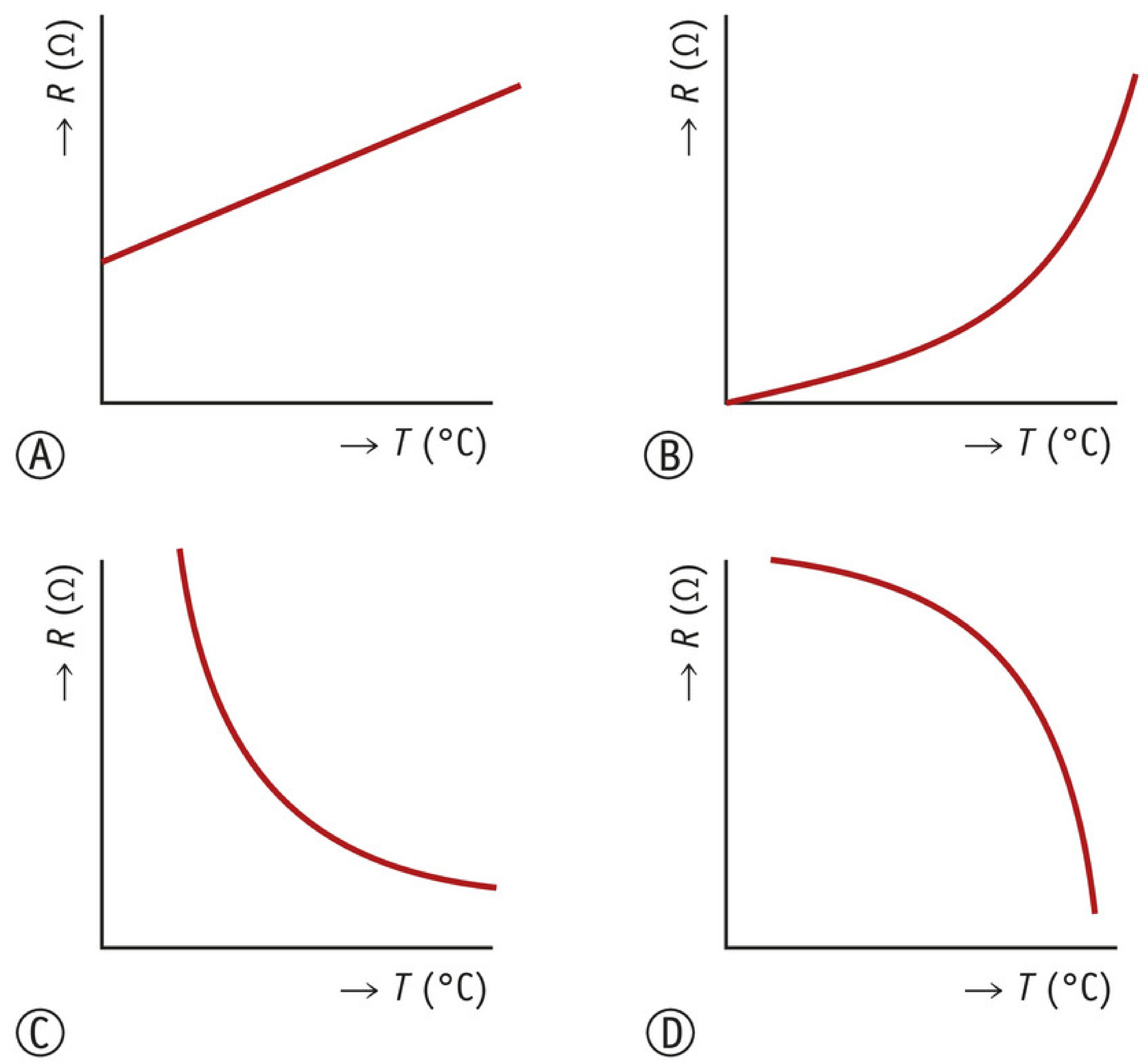
Energy-saving bulb for pocket torch: 3.5 V, 0.7 W, 200 mA. Fitting = E10 Clear

Calculate the resistance of the bulb if it is lit at the correct voltage.

6 State whether the following statements are true or false.
a The brighter the light that falls on an LDR, the higher its resistance will be.
b When the temperature of an NTC thermistor rises, its resistance falls.
c The resistance of most wires gets lower as their temperature rises.
d According to Ohm's law, voltage is directly proportional to current.

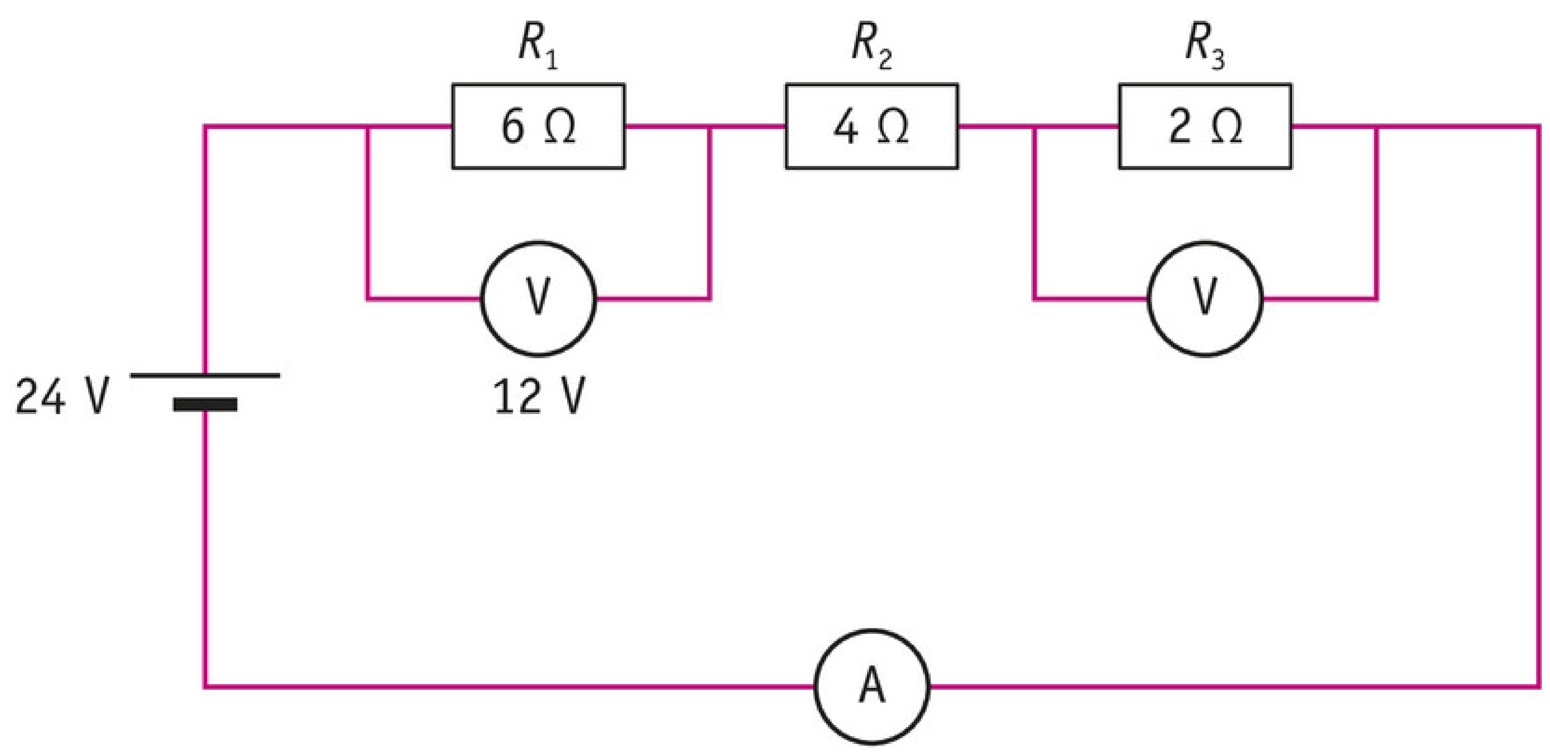
7 A current of 20 mA runs through a 600 Ω resistor. Calculate the voltage across the resistor.

8 The resistance of an NTC thermistor is related to the temperature.
Which of the graphs in figure 57 correctly represents this relationship?



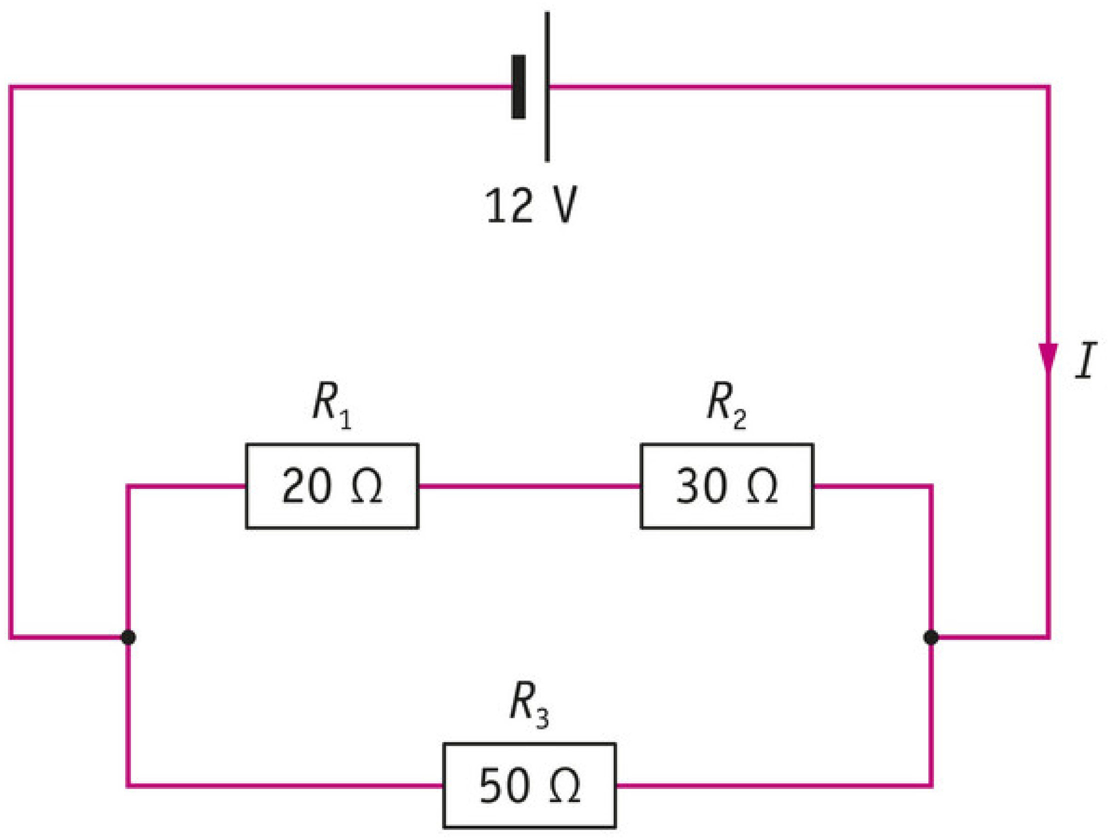
▲ **figure 57**
Which graph is of an NTC thermistor?

9 Figure 58 shows three resistors that are connected in series.
a Explain why the voltmeter indicates a voltage of 12 V across resistor 1.
b Calculate the voltage across resistor 3.



▲ **figure 58**
three resistors in series

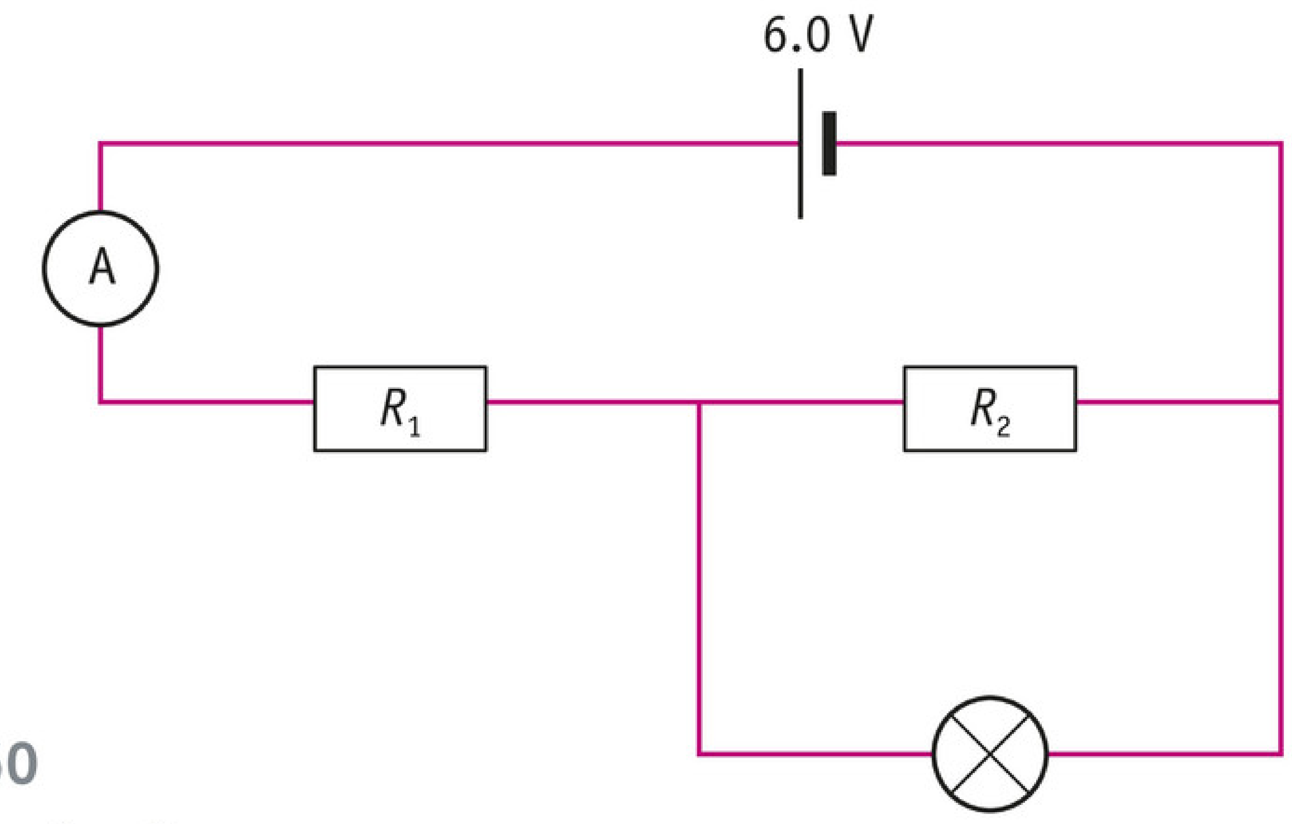
10 What is the resistance of the circuit in figure 59?
A 100 Ω
B 50 Ω
C 25 Ω
D 0.5 Ω
E 0.04 Ω



▲ **figure 59**
a mixed circuit

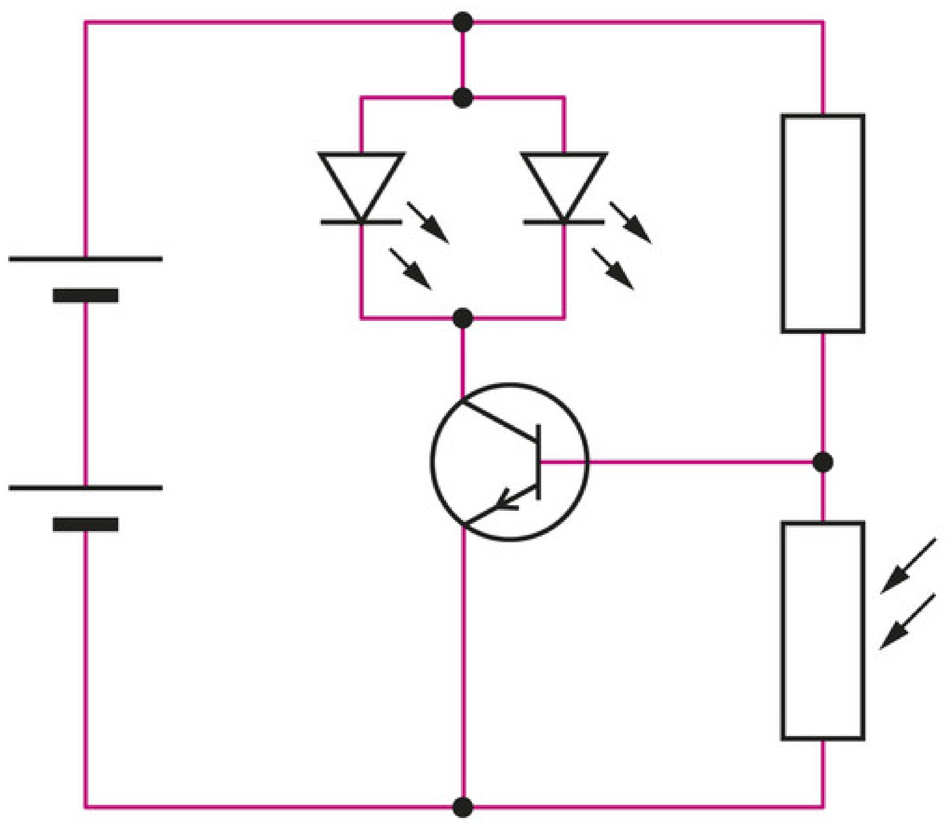
11 John has a number of identical bulbs of 6 V/0.1 A. He connects these bulbs one by one to a power supply box which is set to 6.0 V. The supply is protected by a 0.5 A fuse. John connects all the bulbs up in parallel.
State whether the following statements are true or false.
a The more bulbs John connects, the higher the equivalent resistance gets.
b The more bulbs John connects, the higher the total current gets.
c If one bulb burns out in John's circuit, all other bulbs will go out.
d When John connects a new bulb, all other bulbs will become less bright.
e John can only connect five bulbs, before the fuse blows.

12 Abigail has made the circuit shown in figure 60. The resistors R_1 and R_2 in the figure are both 2.0 Ω. The ammeter shows 2.5 A.
Calculate or explain:
a the voltage across R_1.
b the voltage across R_2.
c the current through R_2.
d the current through the bulb.



▲ **figure 60**
Abigail's circuit

13 Gary has bought a rear bicycle light that is powered by a battery. The rear light turns on by itself when it gets dark outside. Figure 61 shows you the circuit diagram.
In this automatic circuit, what is:
a the sensor?
b the switch?
c the actuator?



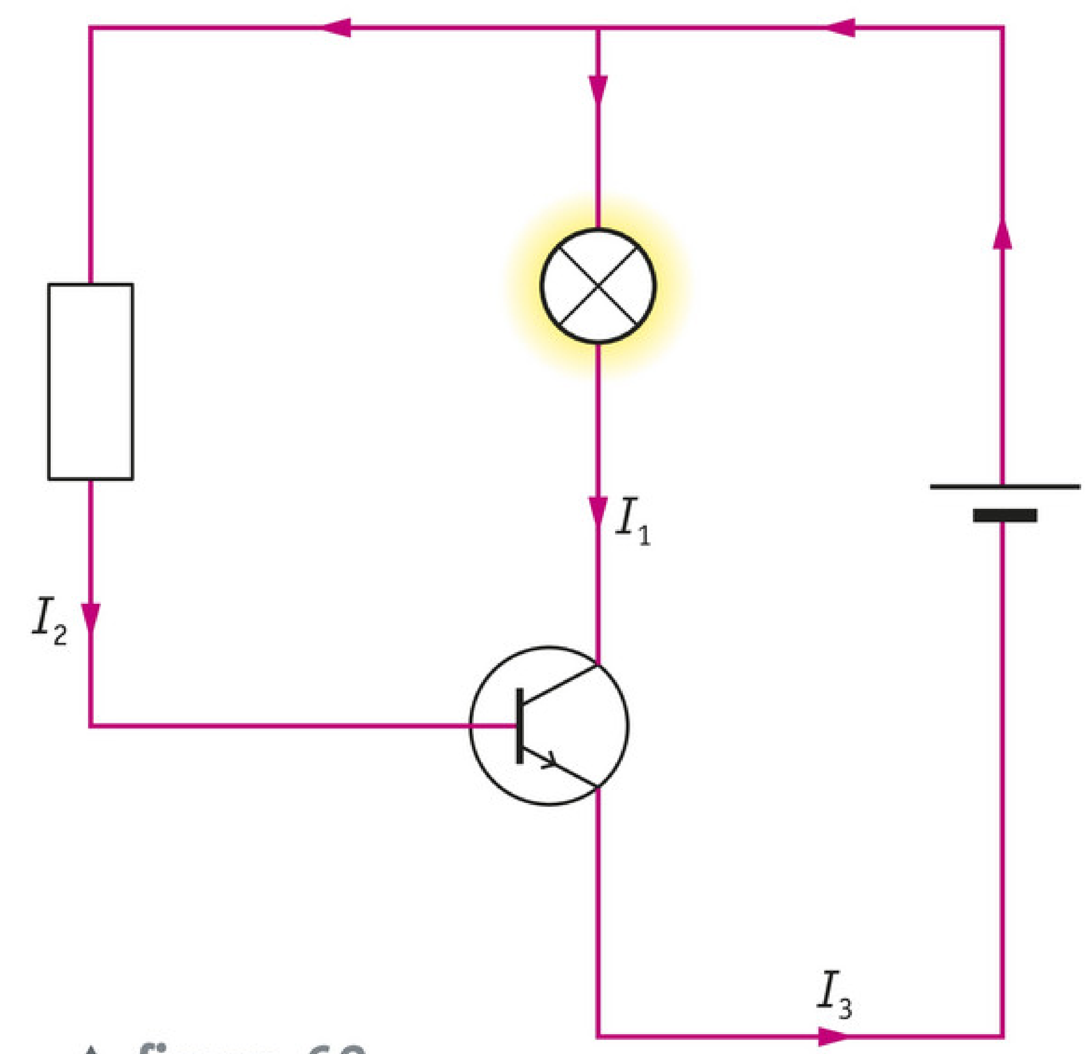
◀ **figure 61**
the circuit diagram for a rear bike light

14 Continuation of exercise 13.
Select the correct options.
When the amount of light decreases in the evening, the resistance of the LDR becomes *higher* / *lower*. As a result, *more* / *less* current flows through the base of the transistor. The transistor therefore switches to the *ON* / *OFF* position. This switches the LEDs *on* / *off*.

15 Irene makes a circuit to test a transistor (figure 62). She measures the current at three points (I_1, I_2 and I_3). The values that she has measured are (from largest to smallest): 91 mA, 89 mA and 2 mA.

- **a** How large is current I_1?
- **b** How large is current I_2?
- **c** How large is current I_3?

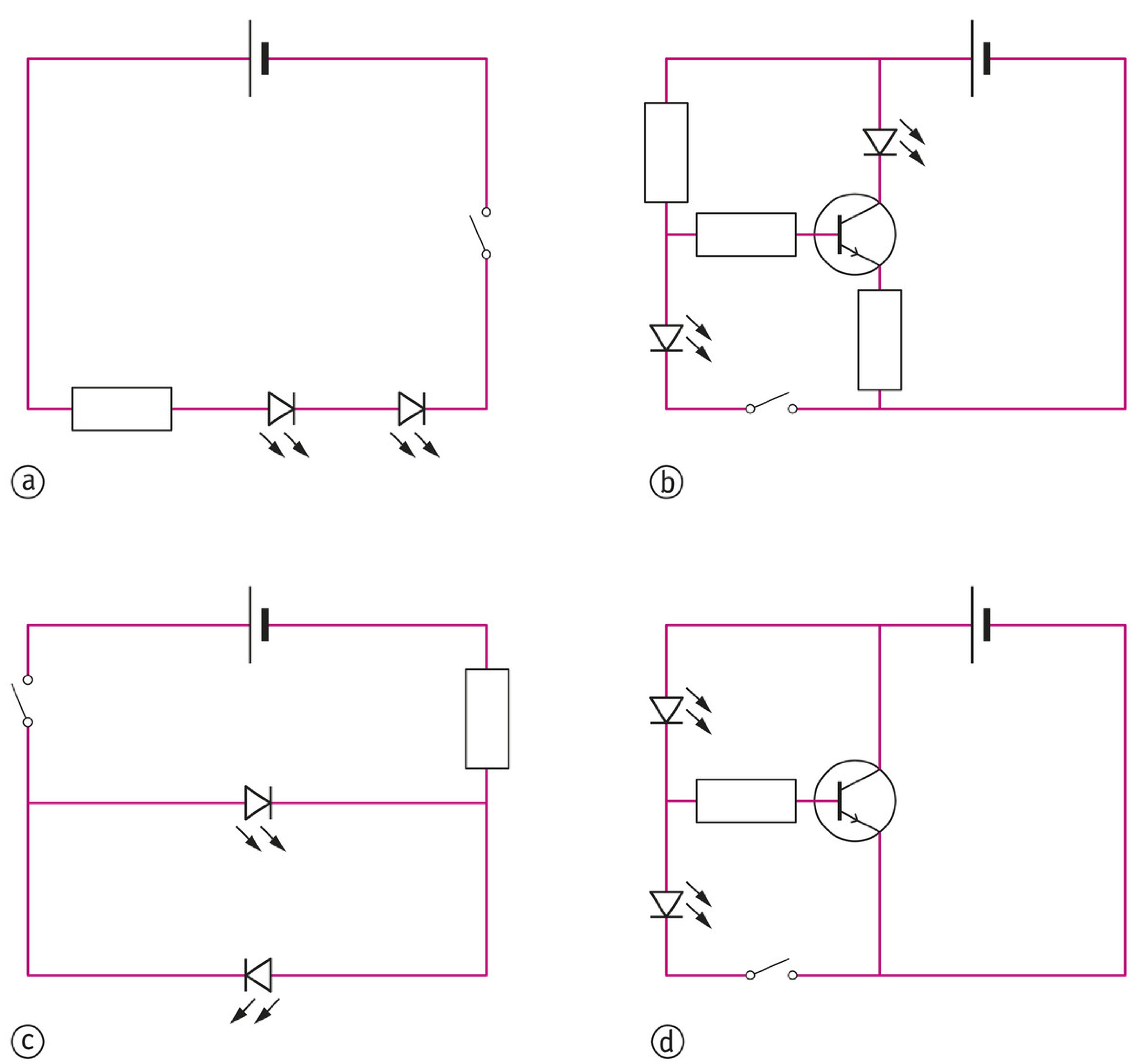
16 Isabel wants to make a warning lamp for the toilet. If the toilet is occupied (when the switch is closed), one LED is lit. If the toilet is not occupied (the switch is open), the other LED is lit.
Which design in figure 63 makes this possible?

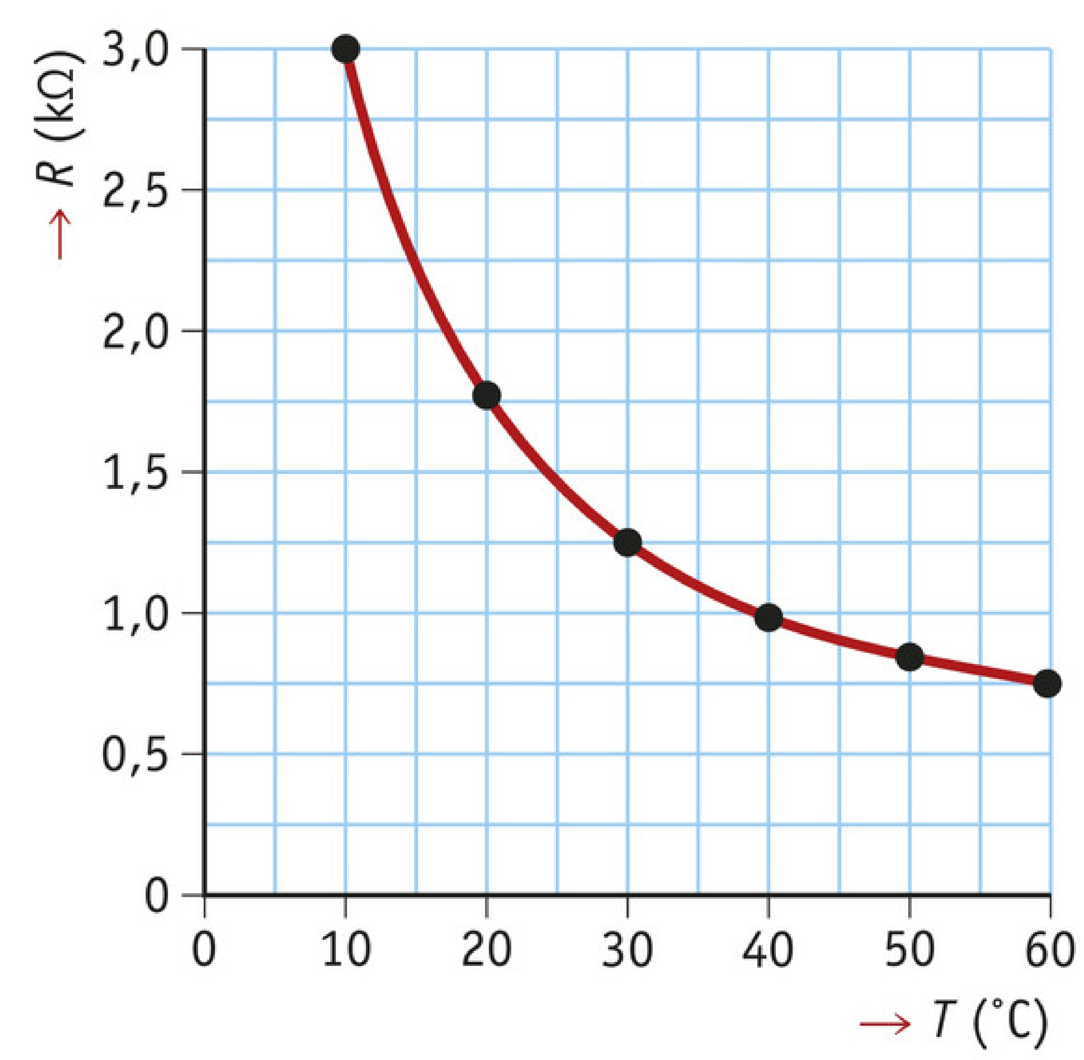


▲ **figure 62**
How to test a transistor.

17 Raphael is doing a series of experiments using an NTC thermistor as a temperature sensor. Before starting, he has measured the relationship between the temperature and the resistance (figure 64).
In one of Raphael's experiments, a current of 6.0 mA flows through the NTC thermistor. At that moment, the voltage across the NTC thermistor is 10.8 V.
Calculate the temperature of the NTC thermistor.

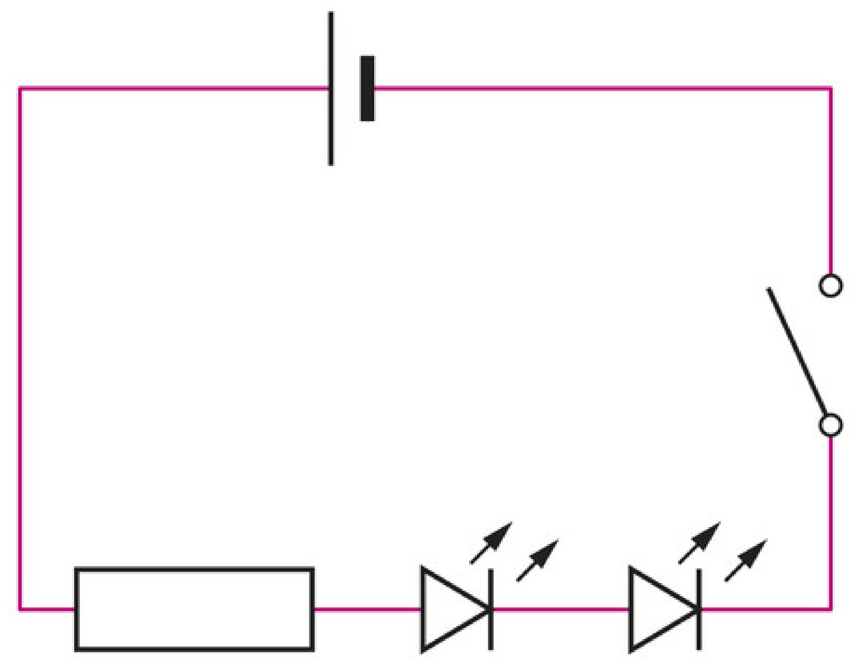
▼ **figure 63**
Which is the correct circuit?





▲ **figure 64**
the resistance of an NTC thermistor at different temperatures

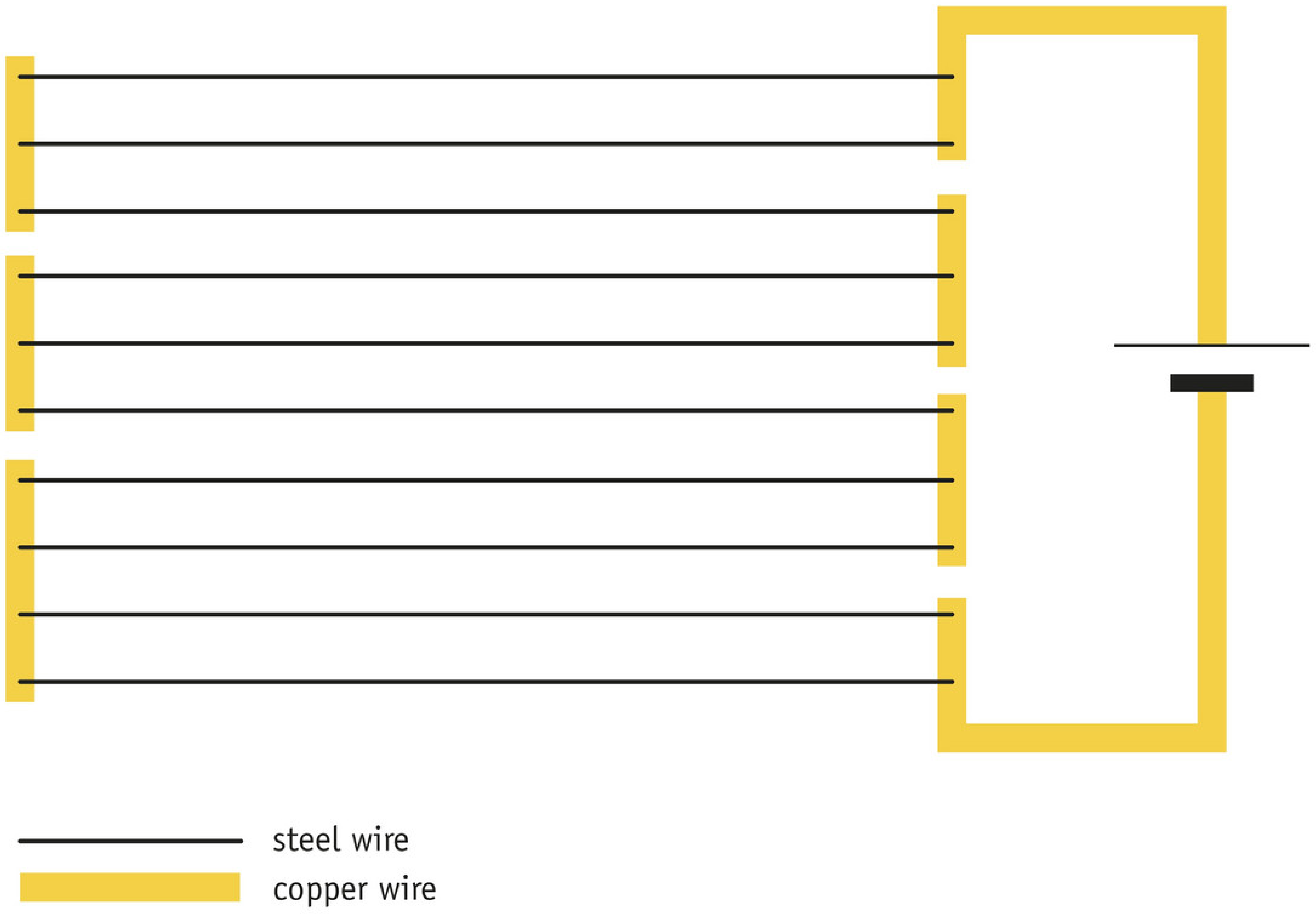
18 Maya has made a series circuit with two identical LEDs (1.6 V/20 mA), a resistor and a 9.0 V battery (figure 65).
- **a** Why has Maya connected a resistor in series with the LEDs?
- **b** Calculate what value this resistor must be to make sure the LEDs are lit properly.



▲ **figure 65**
Maya's circuit

***19** Damien has noted that the rear window heater of a car is made of a combination of metal wires. He decides to make a similar heater himself. He therefore cuts a 7.5 m steel wire of 1.5 Ω into ten equal pieces. After that, he connects the wires using thick copper wire with a very low resistance (figure 66).
- **a** Calculate the total resistance of Damien's rear window heater.
- **b** Damian connects the circuit to a 12.0 V car battery.
  Calculate the total current through the wires to and from the battery.
- **c** Soon there is smoke in some places.
  Explain which two steel wires have become too hot now.

▼ **figure 66**
Damien's rear window heater



***20** A burglar alarm uses a wire on the window as a sensor. A buzzer will sound if someone smashes the window and breaks the wire. A red LED will light up too. The buzzer works on a voltage of 12 V, the LED on a voltage of 1.2 V.
- **a** Think up and draw a circuit diagram for this burglar alarm.
- **b** What minimum voltage must be provided by the voltage source?
- **c** How did you make sure that the LED is lit at the correct voltage?

***21** Two resistors are connected in parallel to a 9.0 V battery. One has a resistance of 100 Ω. The resistance of the other resistor is unknown. The total current is 200 mA.
Calculate the unknown resistance.

***22** Two identical resistors were first connected in series and then in parallel.
What is the ratio between the equivalent resistance in the first case and in the second case?

SEARCHING FOR

Nils Kerkhoven, an archaeologist, is having a good time. He patiently checks the ground with a metal detector and a headphone on his head. Sometimes his patience is rewarded and his headphone starts to beep excitedly. He bends over and stirs up the soil. "Bingo! Here's another one." He holds up a small, roughly circular object. He has found dozens of them in the past few weeks. Gold and silver coins from the Early Middle Ages, which were hidden by an inhabitant of Utrecht around the year 700, and which have shown up after more than thirteen centuries.

METALS

There is an archaeological dig at the Domplein in Utrecht. Archaeologists are searching the soil carefully to find relics from the past. It is not the first time. People also went digging at the same location in 1949 but only two coins were found then. The gold and silver discs are so small that you can hardly find them without using detectors. But it is different now. Thanks to the metal detector and Nils Kerkhoven's patient searching, more than fifty coins have already been collected, and the number is still rising.

It is not a good idea to start pile-driving when there could be a thousand pounder lying somewhere under the ground.

Searching with a metal detector

A metal detector acts as an extension of your senses. A metal detector sees the things that you cannot perceive yourself, such as a coin underneath the sand, for example. When the device detects a possibly interesting object, it starts to beep. You know then that there might be a coin in the soil at that location. You can even tell by the beeps in the headphone if it is a gold or silver coin.

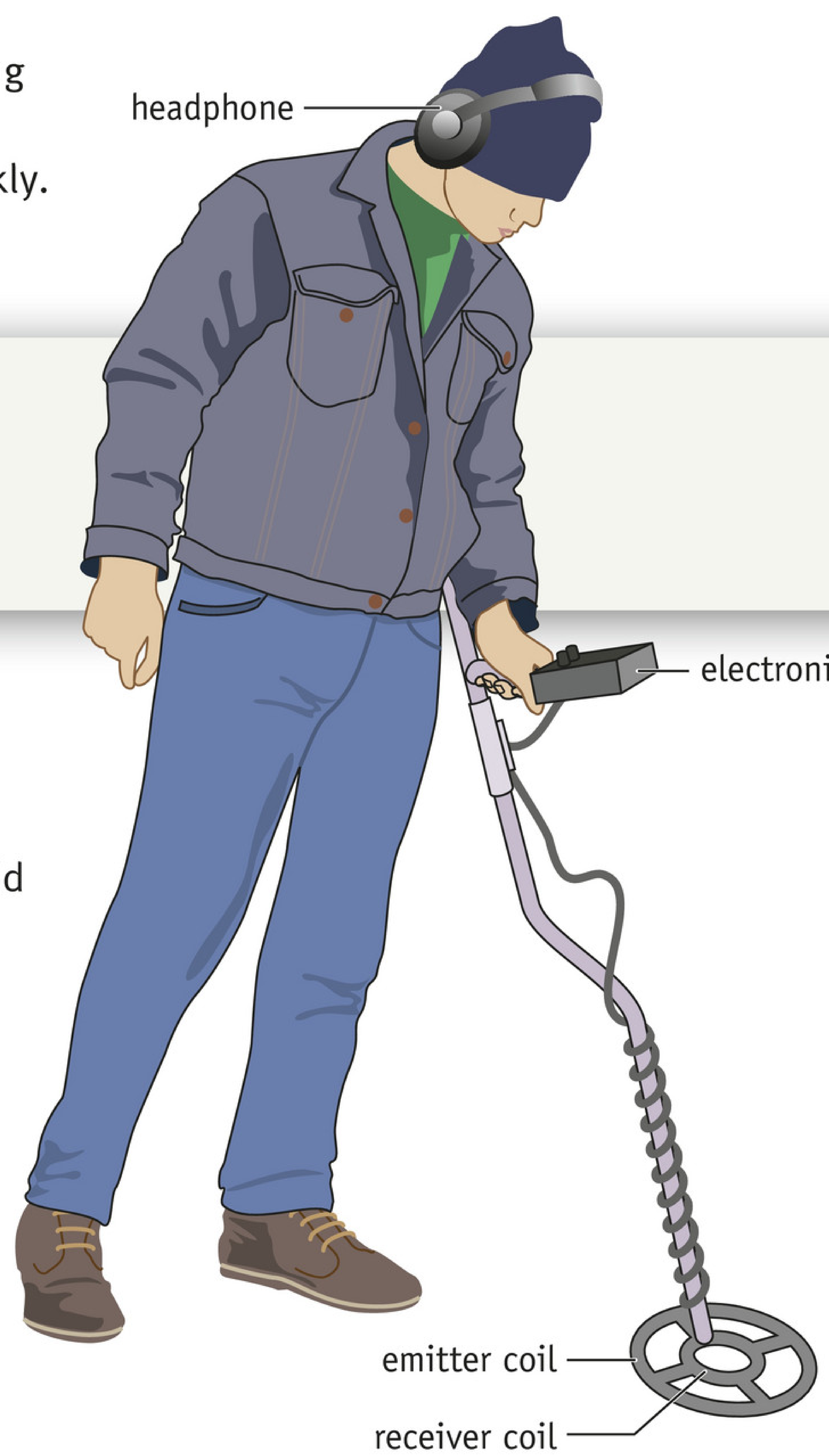
The most popular type of metal detector has two coils, a transmitter coil and a receiver coil. The transmitter coil produces a magnetic field that penetrates some distance into the ground. The receiver coil acts like an antenna: it registers if a (weak) magnetic field is 'reflected' from the ground. This signal is analysed by the electronics in the metal detector, which then produces a corresponding beep.

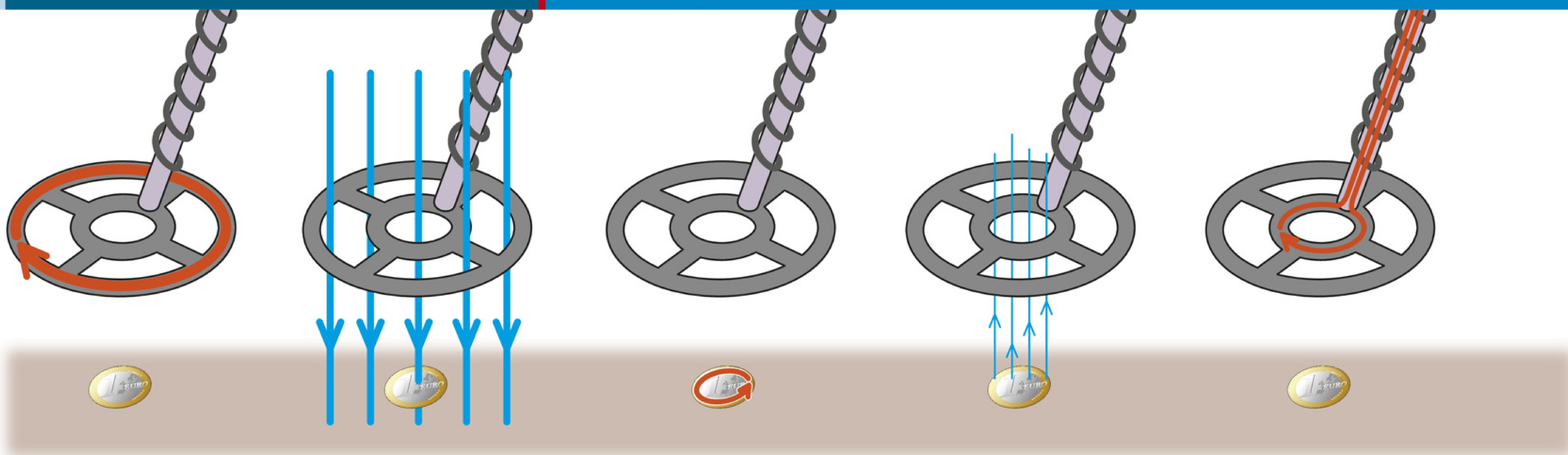
Eddy currents

A metal detector makes clever use of the facts that electricity can generate magnetism and that magnetism can generate electricity. The search starts with a high-frequency alternating current that goes through the transmitter coil. This alternating current generates a magnetic field that changes just as quickly. Each time the current changes direction, the magnetic field does too.

When a changing magnetic field encounters a metal object, an *eddy current* is generated in the metal. This name was chosen, because the current rotates in a more or less circular motion, like a whirlpool. The eddy current then generates a magnetic field in turn, far weaker than the field of the transmitter coil and in the opposite direction.

However, the receiver coil is completely shielded from the strong magnetic field of the transmitter coil. As a result, the receiver coil only 'senses' the weak magnetic field from the eddy current. This field generates a tiny current in the receiver coil, at the same frequency as the alternating current of the transmitter coil. This small current tells the electronics that a metal object has been detected.





An alternating current goes through the emitter coil, generating a changing magnetic field. This creates an eddy current in the coin, which in turn generates a weak magnetic field that induces a weak current in the receiver coil.

Searching for cables and bombs

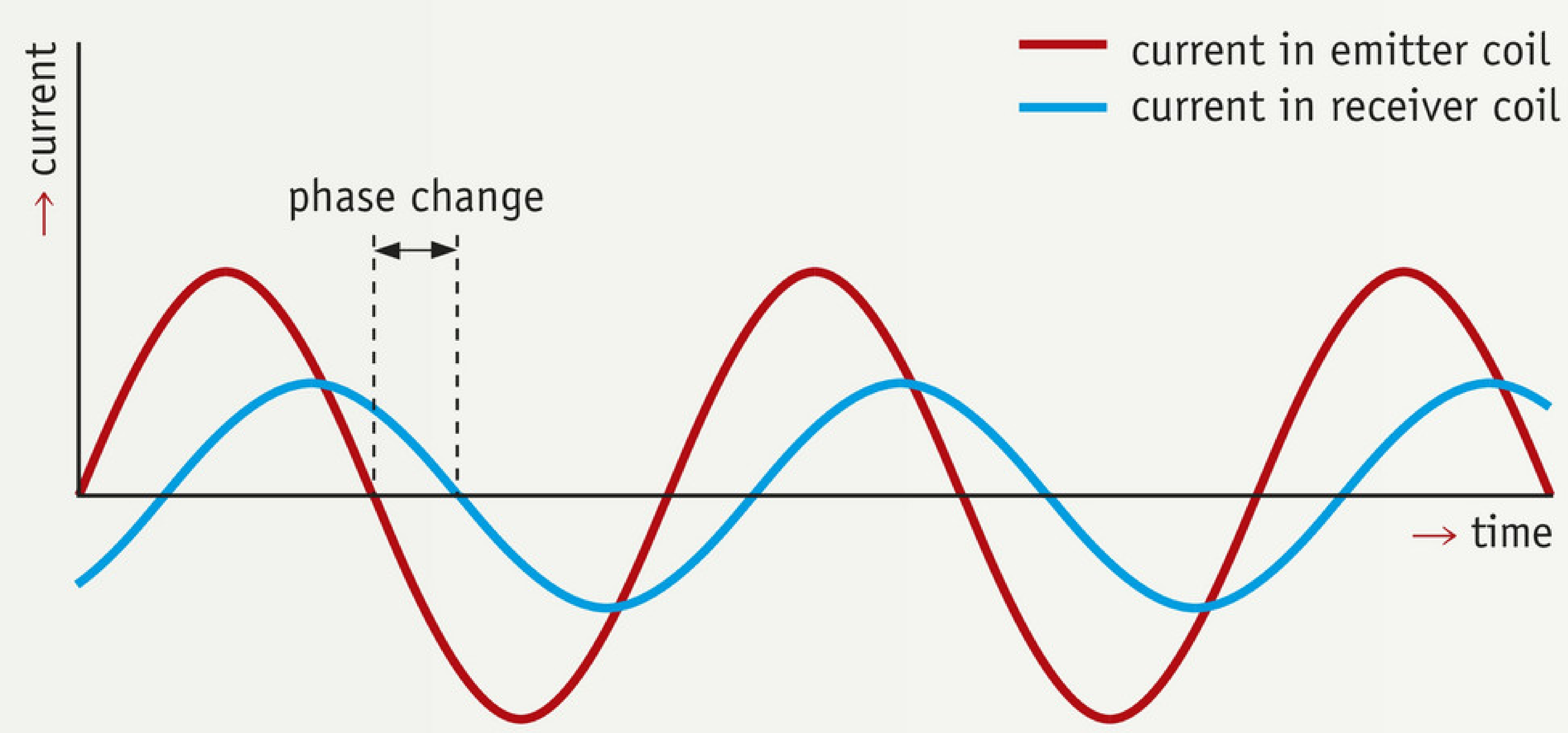
Metal detectors are not only used by archaeologists and people who like treasure hunting. Companies also use them, for example to map pipelines and cables before excavation work starts. Large claims for damages may result if a digger breaks a water pipe or cuts an electricity cable. Checks with a metal detector can make sure this will not happen.

Another application is searching for unexploded bombs from World War II. If there is a suspicion that there may still be bombs in the ground at a construction site, the contractor cannot just start working. It is not a good idea to start pile-driving when there could be a thousand pounder lying somewhere under the ground. The site is searched with a metal detector first. Ground radar is also often used for this.

Another application is the security gates that airline passengers have to pass through before departure. The gate triggers an alarm if you have any metal objects on you, no matter whether it is a bunch of keys, a coin or a knife. The security staff have portable detectors so that they can find the metal object quickly. Speed is important, because the alarm gets triggered quite often, and even though it is almost always something innocent, the cause must be found before you are allowed through.

Identifying metals

The rotating motion of the water as a sink empties always takes a little time to build up. It is the same for the eddy currents generated by a metal detector. The current in the object builds up just a tiny fraction of a second later than the current in the emitter coil. This is called a phase difference.
The phase difference is not the same for all metals. Some metals react quickly to a changing magnetic field, others more slowly. The phase difference is much larger for a silver coin than for an aluminium bottle top. It is caused by the electrical properties of the metal, for example: whether it is a good conductor or a poor one.
A metal detector uses the phase difference to identify the various metals. The electronics measures by how much the received signal lags the emitted signal and concludes from that what metal it is.



Detecting cars

The same detection technique is used in ‘intelligent’ traffic lights. The control system that handles this type of traffic light can see if there are cars at the stop lines and

adjusts its control behaviour to suit. A driver will get a green light immediately if there are no any other cars waiting, for instance.

The sensor in this kind of 'intelligent' traffic light system is a rectangular loop of insulated wire that is embedded in the road surface. A groove has to be cut into the asphalt before the detection loop is put in place. Road workers place the wire in it and seal the groove afterwards. You can see the scar for a long time afterwards, until the road surface is paved with another layer of asphalt.

The detection loop generates an eddy current in the metal underside of the car when it is right above the loop. This is done in the same way as in the metal detector, by having a high-frequency the detection loop. The magnetic field from the eddy current has an effect on the current through the detection loop. This tells the control electronics that there is a car above the loop.

Successful technology

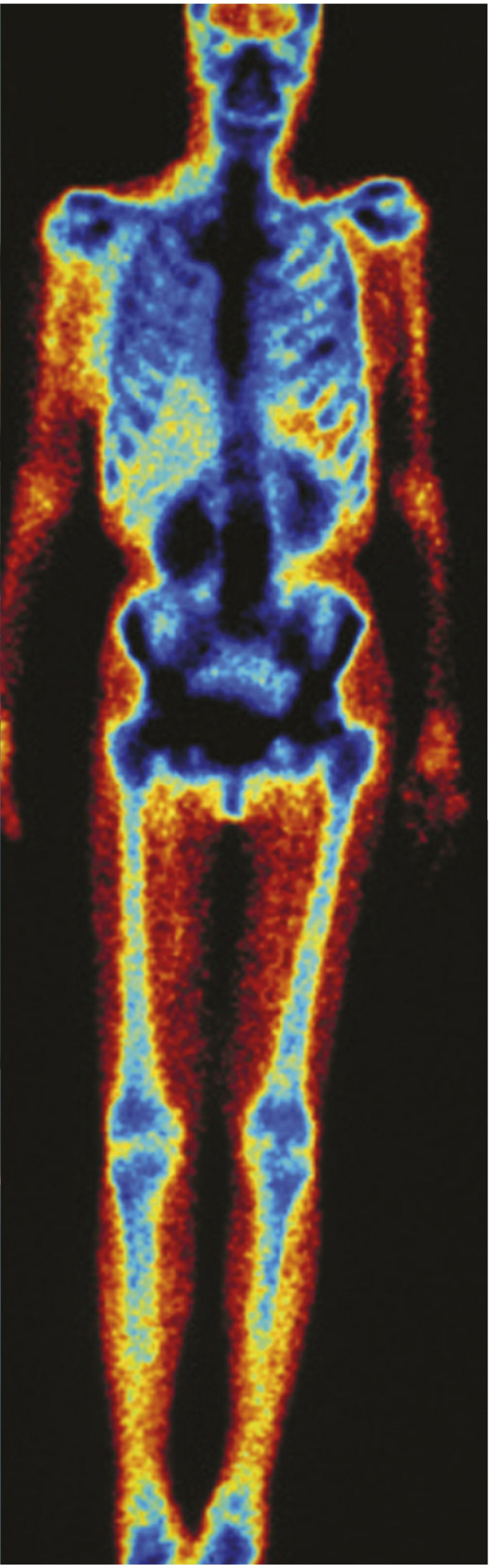
The perfect detection system sees what it has to see under all conditions, cannot be misled, has no problems with faults and cannot be damaged. Such a system cannot be designed just like that: you need reliable sensors for it, plus smart electronics that takes everything into account. Even though every design has its limitations, some detection systems are pretty close to perfection – as is shown by the variants on the metal detector theme that are used every day.

Exercises

1 You can detect buried coins with a metal detector.
Explain if the following are also important for the detection:
- **a** the size of the coin.
- **b** how deep the coin is in the ground.
- **c** what kind of metal the coin is made of.
- **d** whether the coin is lying flat in the ground or standing upright (on its edge).

2 Metal detectors are used in the food industry for scanning products.
- **a** What 'non-food objects' can be detected in the food in this way?
- **b** What kind of foreign objects might these be? Think up an example for yourself.

3 Search the Internet for information about the detection loops in motorways.
- **a** How many motorway detection loops like that do you think there are in the Netherlands?
- **b** Explain how detection loops can help you find out how fast a car is going.
- **c** For what purposes is data collected from detection loops?
- **d** Why do the detection loops sometimes fail to see motorbikes?



7

Radioactivity

Working with ionising radiation

Radioactive substances emit radiation. This radiation is used at hospitals to detect and treat diseases. Rigid safety regulations are always in place, because the radiation also can make healthy people ill.

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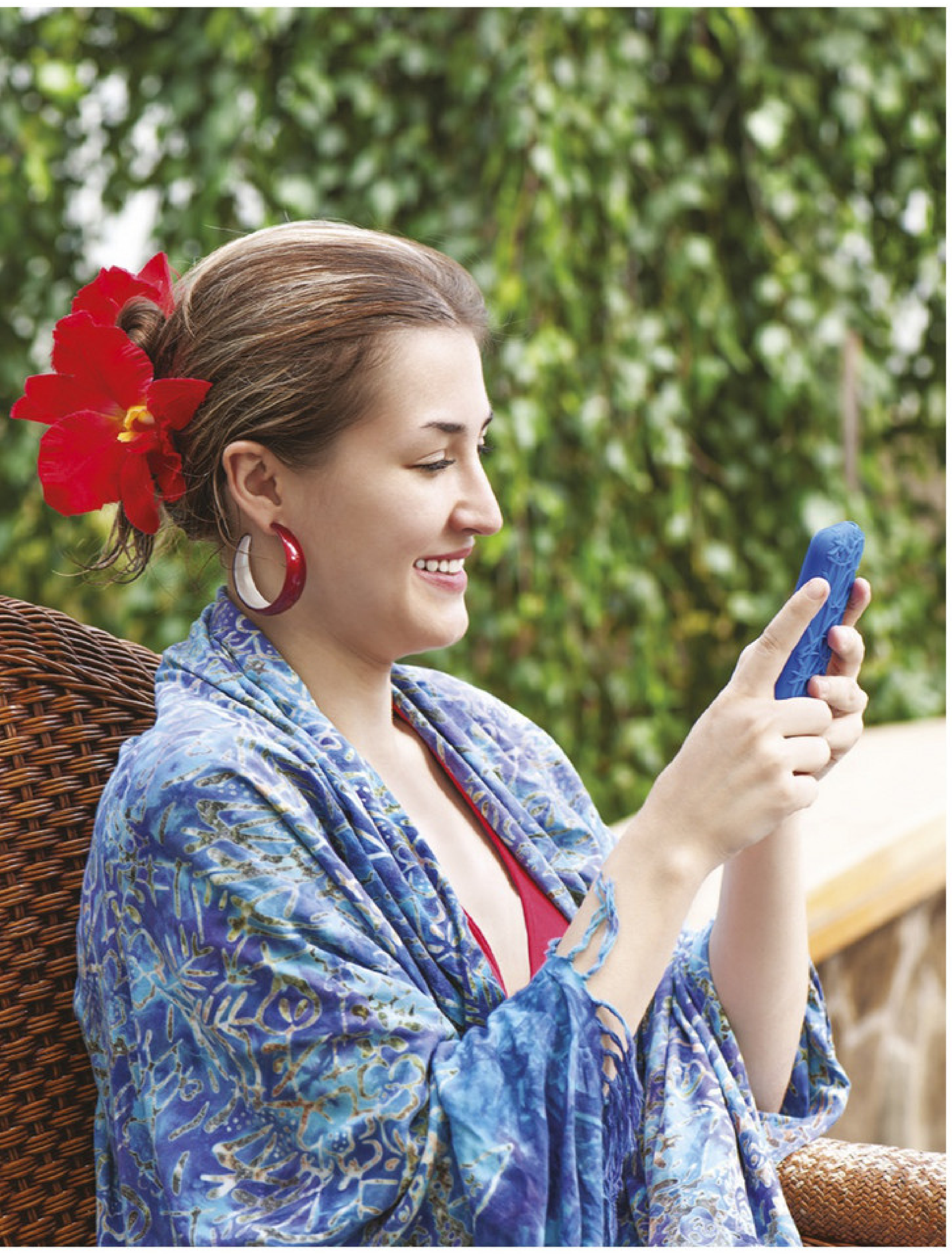
1 Types of radiation



▲ figure 1
transmitting using your telephone

When they hear the word 'radiation' a lot of people think of nuclear energy and radioactivity. But there are many other types of radiation. Your mobile phone is a radiation source too, just like the microwave and the remote control. Even your body continuously emits infrared radiation.

Transmitting and receiving

You can only use your mobile if you have 'coverage'. There has to be a transmitter mast in the neighbourhood that your phone can communicate with. Information is then continuously exchanged between the antenna of your phone and the antenna on the transmitter mast. In turn, the mast also communicates with other transmitter masts further away.

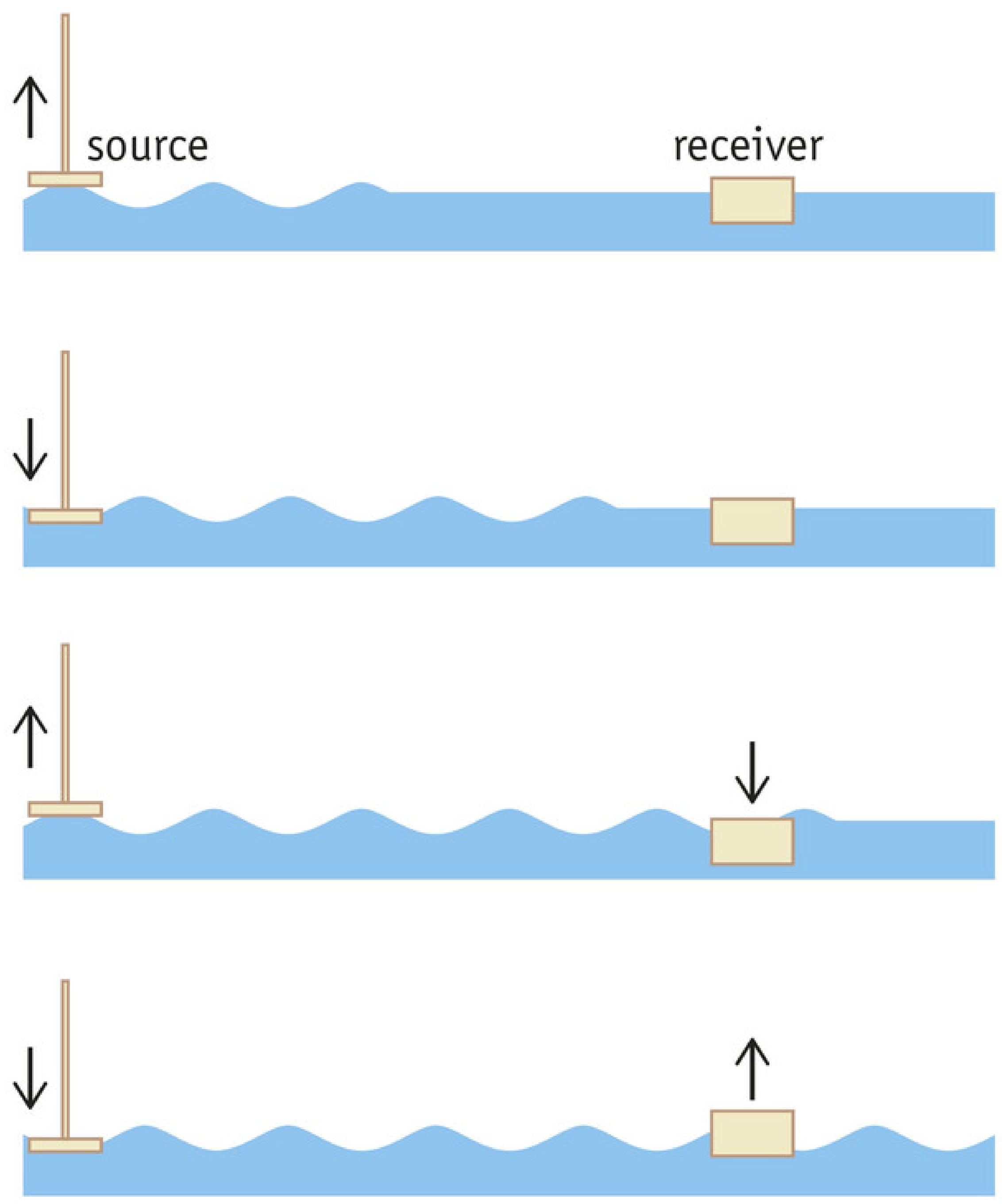
When your phone is transmitting, an alternating current goes through the antenna (figure 1). The electrons in the antenna move up and down at a high frequency. This movement causes **electromagnetic waves** that move away from the antenna at a speed of almost 300,000 km/s.

When the electromagnetic waves reach the mast, the electrons there start to move too, the electrons in the mast's antenna move up and down in the same way as the electrons in the phone antenna. This creates an alternating current of the same frequency as the alternating current in the phone antenna.

Everything in the communication with your telephone is done digitally, the information is encoded as a long series of zeroes and ones. A phone therefore continuously jumps back and forth between two frequencies when it transmits information, one frequency is for the zeroes, the other frequency is for the ones.

Wavelength and frequency

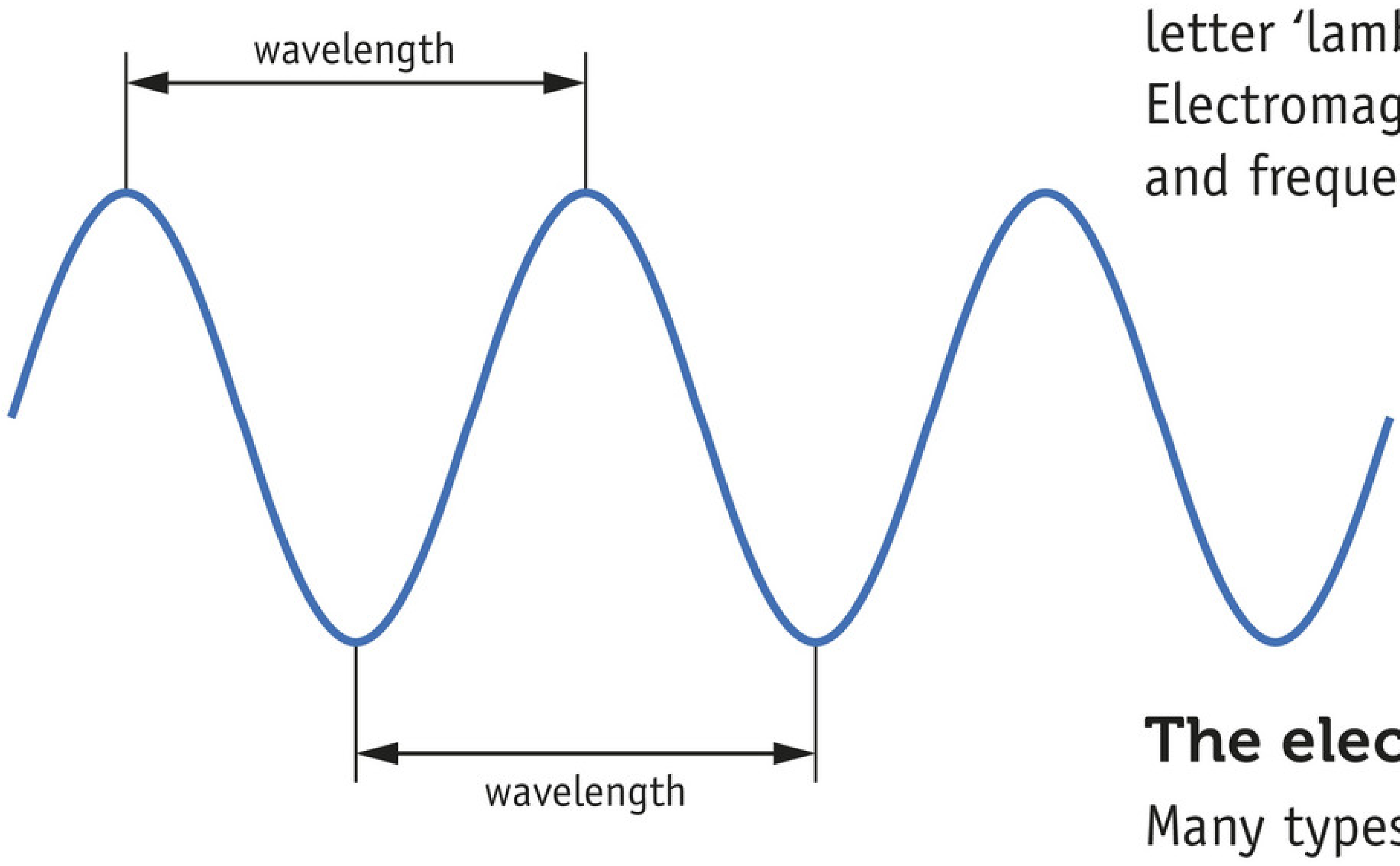
Just like water waves, electromagnetic waves move away from the source. Figure 2 shows you how this works for water waves. The 'source' is an object that goes up and down and makes the water move. The 'receiver' is a wooden block that starts moving up and down, when the waves reach the block. A phone communicates with a transmitter mast (and vice versa) in just the same way.



◀ figure 2
from source to receiver

As well as the similarities, there are also large differences, of course:
- Electromagnetic waves are not restricted to just one plane like water waves, but can move in all directions.
- Electromagnetic waves are not vibrations in a substance like water, but they propagate independently – even through a vacuum.
- Electromagnetic waves always have the same speed in a vacuum, no matter what their frequency is, 299,792,458 ≈ $3.0 \cdot 10^8$ m/s. This speed is called the **speed of light**.

The number of waves created every second is called the frequency. The distance between two successive wave peaks (or wave troughs) is called the **wavelength** (figure 3). The symbol for wavelength is λ, the Greek letter 'lambda'. A phone uses waves with wavelengths of 10 to 40 cm. Electromagnetic waves have a fixed relationship between the wavelength and frequency, every wavelength has just one frequency, and vice cersa.



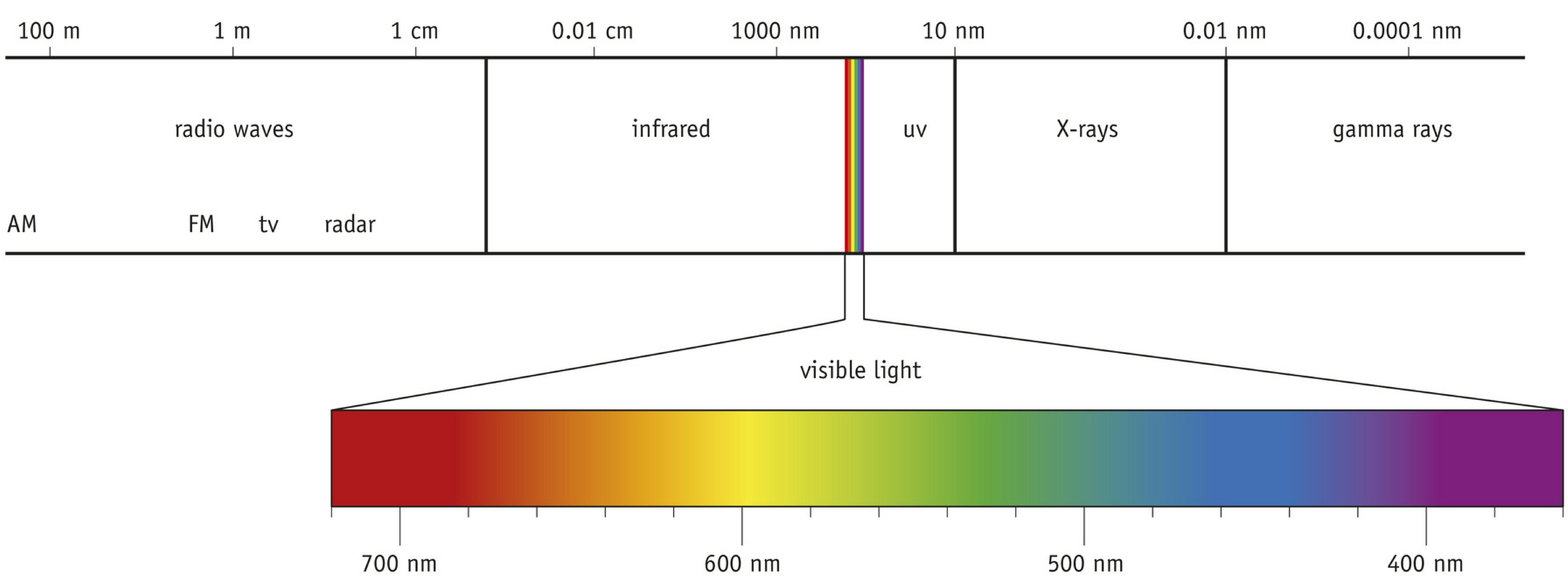
▲ **figure 3**
the length of the wave

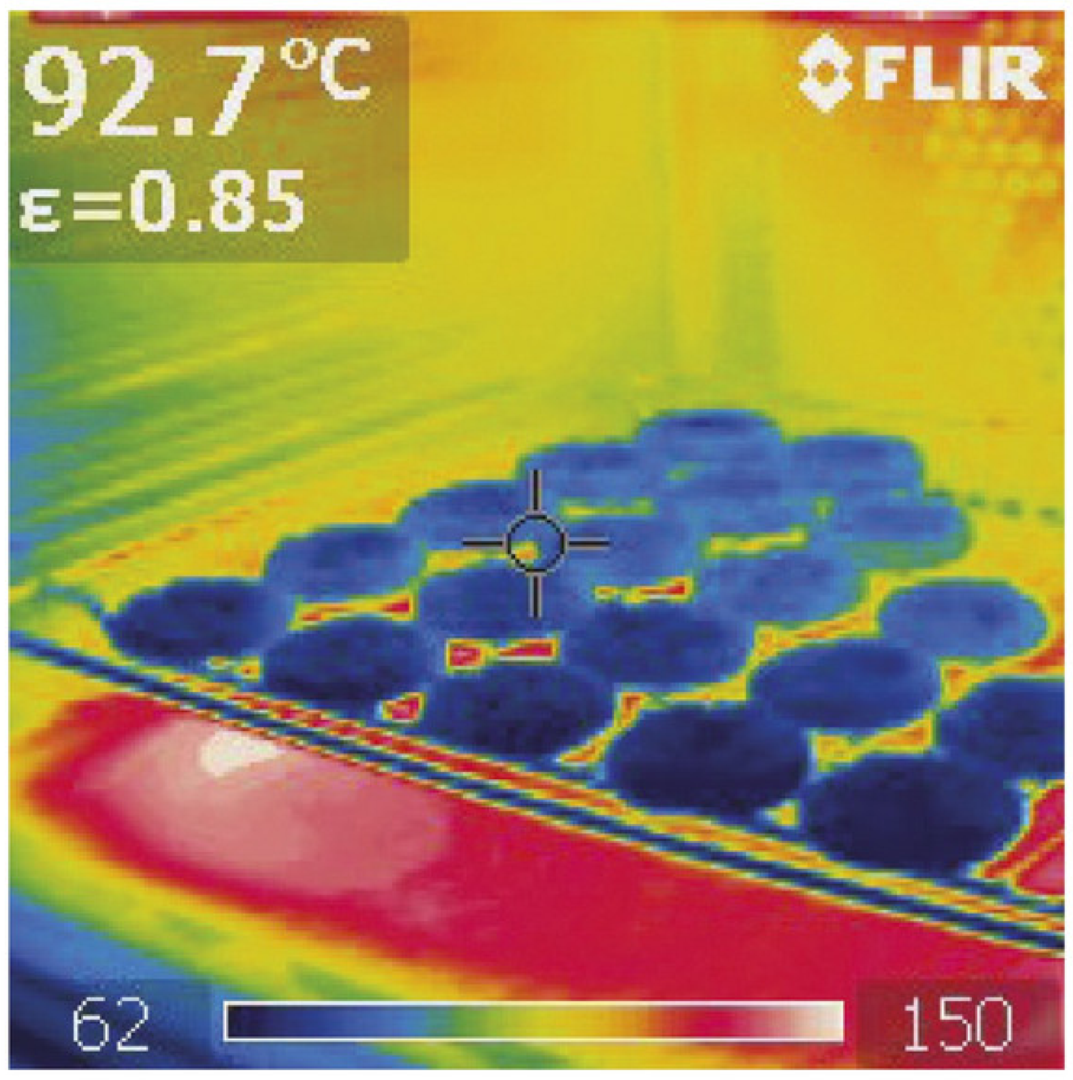
The electromagnetic spectrum

Many types of radiation are made up of electromagnetic waves. For example, light is a type of electromagnetic wave, with wavelengths of between 380 and 780 nm (1 nm = 1 nanometre = 10^{-9} m). Other forms of **electromagnetic radiation** are radio waves, infrared, ultraviolet, X-rays and gamma rays.

Figure 4 shows the different types of electromagnetic radiation ordered by wavelength. This results in an electromagnetic spectrum, ranging from radio waves to gamma rays. The spectrum of light, from the deepest red (780 nm) through to the far violet (380 nm), is just a small part of it.

▼ **figure 4**
from radio waves to gamma rays





▲ figure 5
Infrared photos are used for quality checks in the food industry.

The properties of electromagnetic radiation depend on the wavelength. You can see this in the spectrum of light. Each spectral colour has its own wavelength, as is shown in figure 4. Red light has the longest wavelength and violet light the shortest. If you know the wavelength, you also know what colour the light is.

Light is the only kind of electromagnetic radiation that you can see. Your eyes are sensitive to the colours of 'normal' light, from red to violet. All other forms of radiation are invisible – at least to people. You can only see them with special instruments, like a camera that can take infrared photos (figure 5).

Passing through, absorbing and reflecting

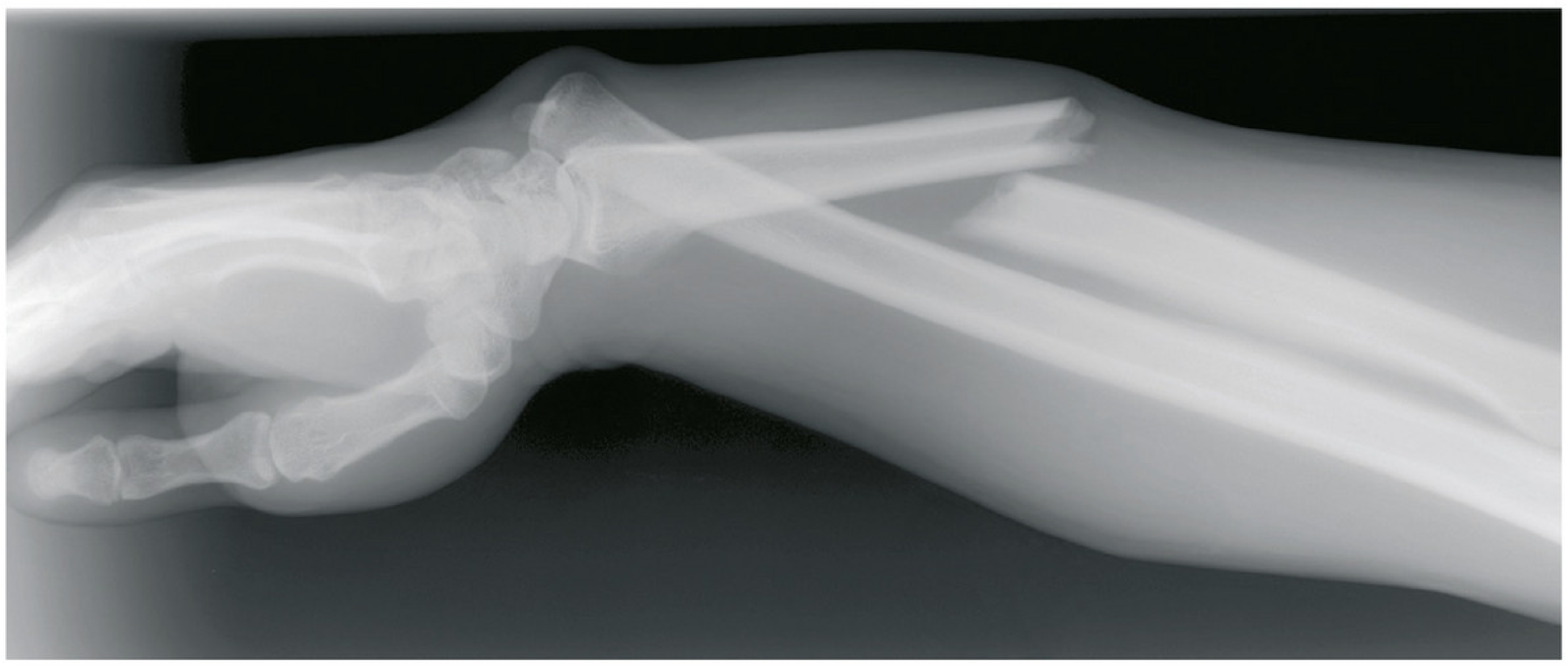
When electromagnetic radiation falls on an object, three things can happen:

- The radiation is allowed to **pass through**. You can see this with sunlight that passes through a glass window.
- The radiation can be **reflected**. You can see this when light is reflected by a mirror or a white wall.
- The radiation can be **absorbed**. You can see this as a dark object heats up in the sunlight.

Your body does not absorb the various types of radiation equally strongly. For instance, radio waves go right through your body but light is stopped. **X-rays** are strongly absorbed by the bones, but the muscles and fatty tissue allow that type of radiation to pass through almost without any problem. This property is used in an X-ray camera.

When an X-ray photo is taken, X-rays fall on parts of the patient's body. This creates a shadow image behind that part of the body, and the image can be recorded. There is a lot of 'shadow' behind the bones and only a little behind the muscles (figure 6). Because the image is negative – light and dark are reversed – this makes the shadows white instead of black.

▶ figure 6
An X-ray photo shows a shadow of the bones.



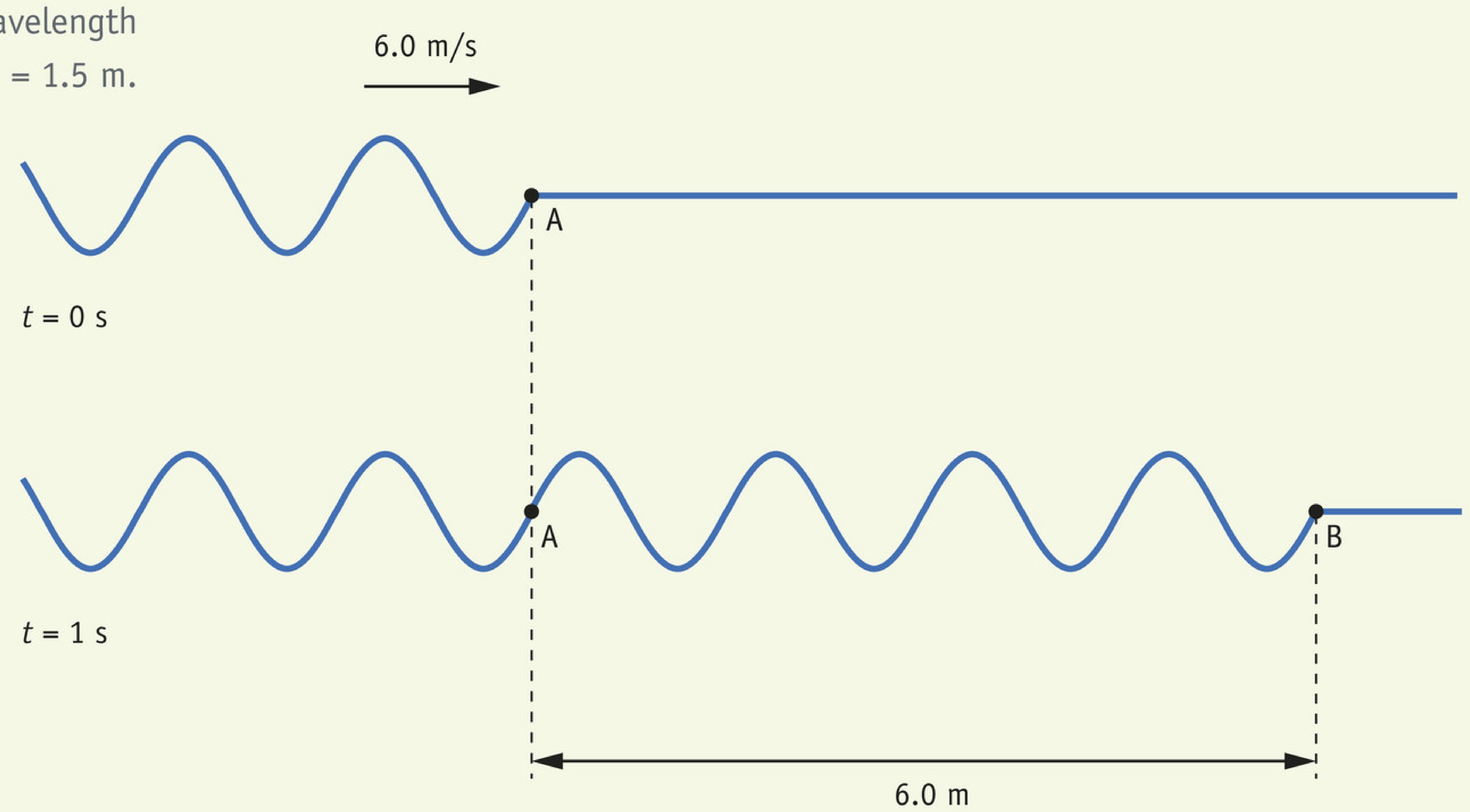
Plus Wavelength and frequency

Any wave motion has a frequency, a wavelength and a propagation speed. There is a fixed relationship between these variables (figure 7). You can calculate the wavelength by dividing the propagation speed (the distance covered per second) by the frequency (the number of waves per second). This is how you find the distance for each wave = the wavelength. Expressed as a formula:

$$\lambda = \frac{c}{f}$$

If you give the speed of propagation c in m/s and the frequency f in Hz, you get the wavelength λ in m.

▼ **figure 7**
Check for yourself that the wavelength of this wave motion is 6.0 ÷ 4 = 1.5 m.



Worked example 1
A laser radiates blue light with a wavelength of 470 nm.
Calculate the frequency of this electromagnetic radiation.

data $c = 3.0 \cdot 10^8$ m/s
$\lambda = 470$ nm $= 470 \cdot 10^{-9}$ m

required $f = ?$

working $f = \dfrac{c}{\lambda} = \dfrac{3.0 \cdot 10^8}{470 \cdot 10^{-9}} = 6.4 \cdot 10^{14}$ Hz

Exercises

1 Answer the questions below.
- **a** How are the electromagnetic waves that are emitted by a mobile phone generated?
- **b** At what speed do electromagnetic waves move through a vacuum?
- **c** What types of radiation have longer wavelengths than (visible) light?
- **d** What type of radiation has wavelengths of between 10 nm and 0.01 nm?
- **e** What three things can happen to radiation that falls on an object?

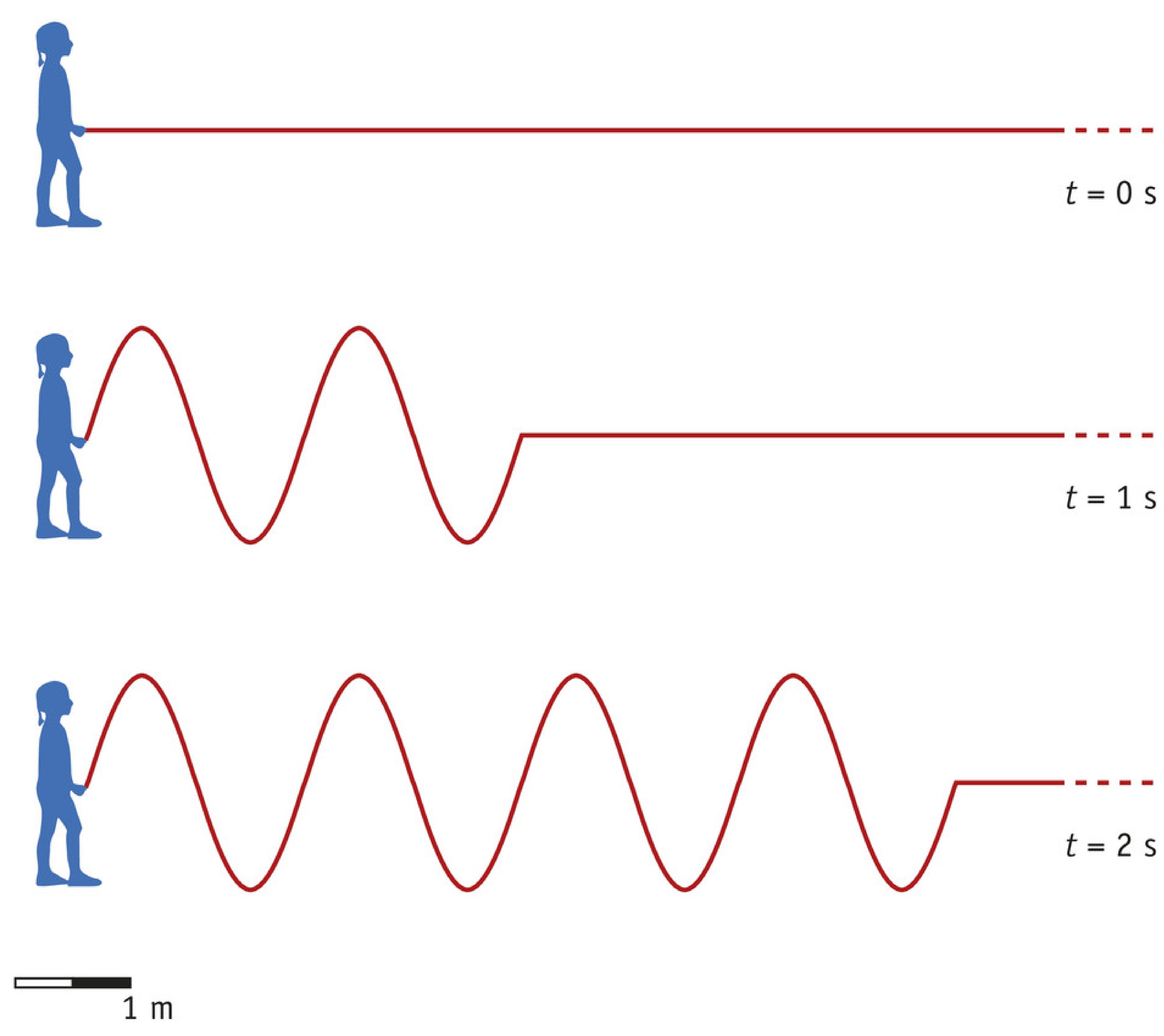
2 Your body is transparent to some types of radiation but not to others. Which type of electromagnetic radiation:
- **a** passes right through your body without being stopped?
- **b** passes through your muscles but not through your bones?
- **c** is completely blocked by your body?

3 You can find all kinds of radiation sources in the world around you. Copy and complete table 1.

4 Elsie creates a wave motion in a skipping rope by moving one end of it up and down. She has attached the other end of it to a wall.
Use the data in figure 8 to calculate:
- **a** the frequency.
- **b** the wavelength.
- **c** the speed of the wave motion.

▼ **table 1** five radiation sources

example of radiation sources	type of radiation
	radio waves
central heating radiator	
	visible light
	ultraviolet
X-ray camera	



▶ **figure 8**
a wave in a rope

***5** It takes a radio signal between 3 and 21 minutes to cover the distance between the planet Mars and the Earth.

a Explain why the time needed can vary so much.

b On 6 August 2012, the Mars rover *Curiosity* landed on Mars. The signal from *Curiosity* only reached Earth after 13 minutes and 48 seconds. Calculate the distance between Mars and the Earth at that moment. Give your answer in millions of kilometres, to one decimal place.

c You did not take the atmosphere of the Earth into account in your calculation in b.
Will the speed of light in the atmosphere be higher or lower than the speed of light in a vacuum? Why do you think that?

d Even if you correct your calculation in b for a different speed of light in the atmosphere, you will still get the same answer.
Explain why.

6 The radiation emitted by a laser has a single fixed wavelength. Table 2 shows six types of lasers and the wavelength that each of them emits.

a Write down the type of radiation that each laser emits.

b Write down the colour of the light for the lasers that emit visible light.

▼ **table 2** six types of lasers

type of laser	wavelength (nm)
argon	1090
helium-cadmium	442
copper	511
krypton fluoride	248
ruby	694
nitrogen	337

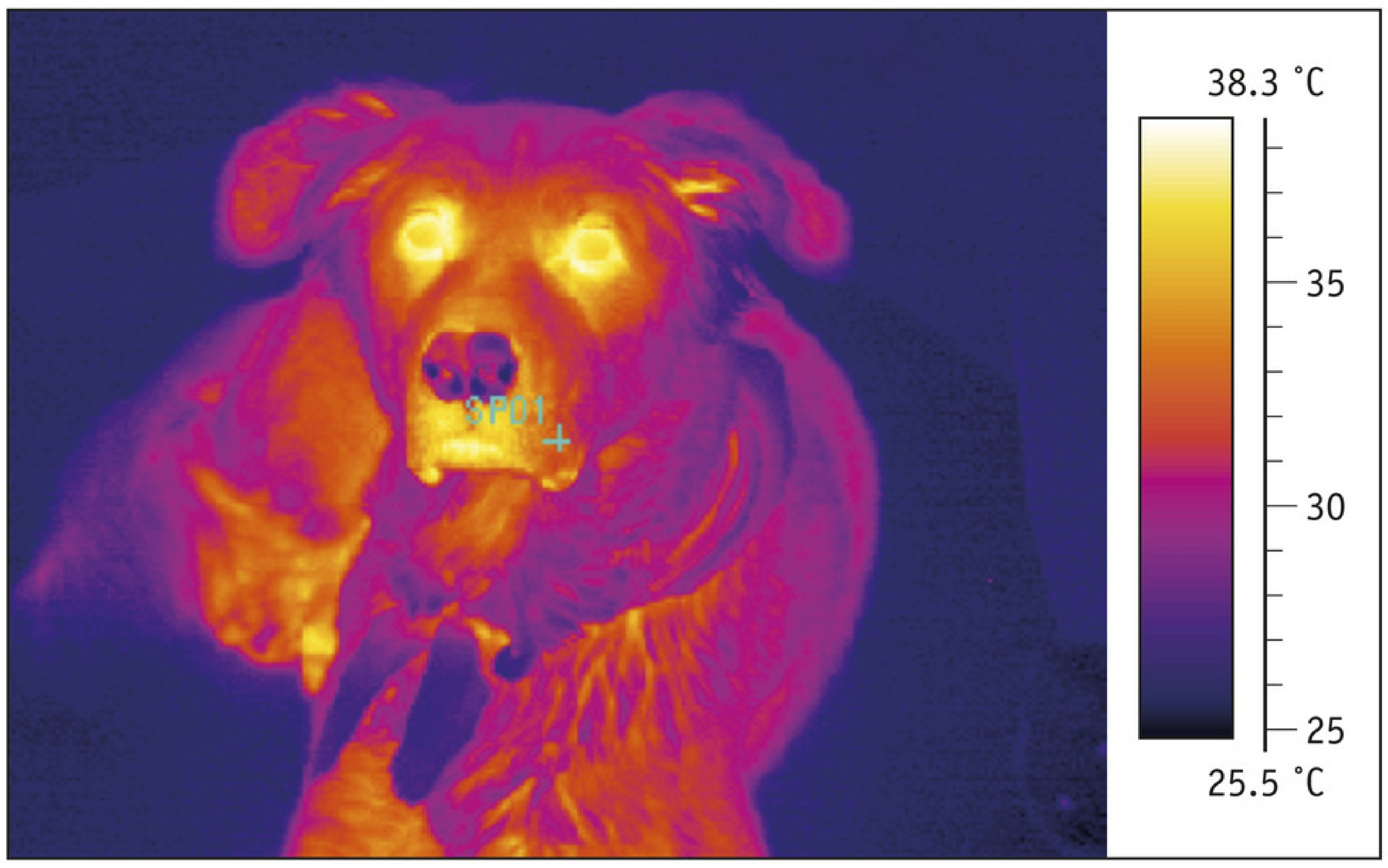
7 Look at the infrared photo in figure 9.

a Which parts of the dog's body are at the highest temperature?

b How high do you think this temperature will be, roughly?

c Which part of the dog's body has the lowest temperature?

d Explain why an infrared camera often makes clearer images at night than in the daytime.

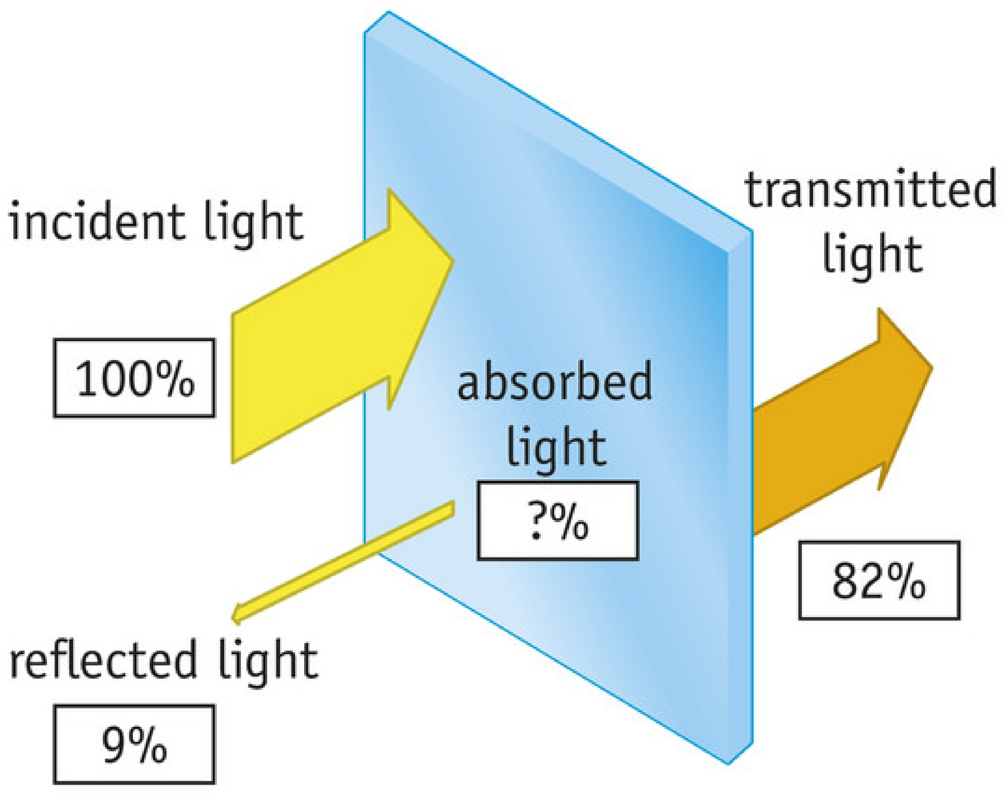


▶ **figure 9**
a dog in infrared

▲ **figure 10**
an X-ray photo taken at a hospital

8 Figure 10 shows an X-ray photo of a man's neck.
- **a** Why is the object in his throat clearly visible? Explain.
- **b** Put the objects below in sequence according to how much they absorb X-rays, from least to most: *air – bones – clothes – object – tissue*.

***9** A factory produces window glass for large buildings. Figure 11 shows you what one widely-used type of glass does with the incident sunlight.
- **a** What percentage of the visible light is absorbed by this type of glass?
- **b** Three windows of this type are put one behind the other in an experiment.
  Show that the amount of radiation that passes through is at least 55%.
- **c** The factory can give the glass a thin coating (a top layer) that reflects part of the light that falls on it.
  What effect does the coating have on the amount of:
  - absorbed light?
  - transmitted light?
  - reflected light?
- **d** An office gets too hot when the Sun shines directly on the windows in summer.
  Does replacing the normal glass with coated glass help? Or will it only make the problem worse? Explain.



▲ **figure 11**
A window transmits radiation, reflects radiation and absorbs radiation.

***10** Sometimes it is easier to write a very large or very small number as a power of ten. Use 'Skills 3' at the back of the book for this exercise.
- **a** Infrared radiation can have a wavelength of 1000 nm. Write this down as a power of 10.
- **b** Figure 4 on page 263 gives an average value for the wavelength of gamma radiation. Write this down as a power of 10.
- **c** How many wavelengths of this gamma radiation would fit into the diameter of an atom?

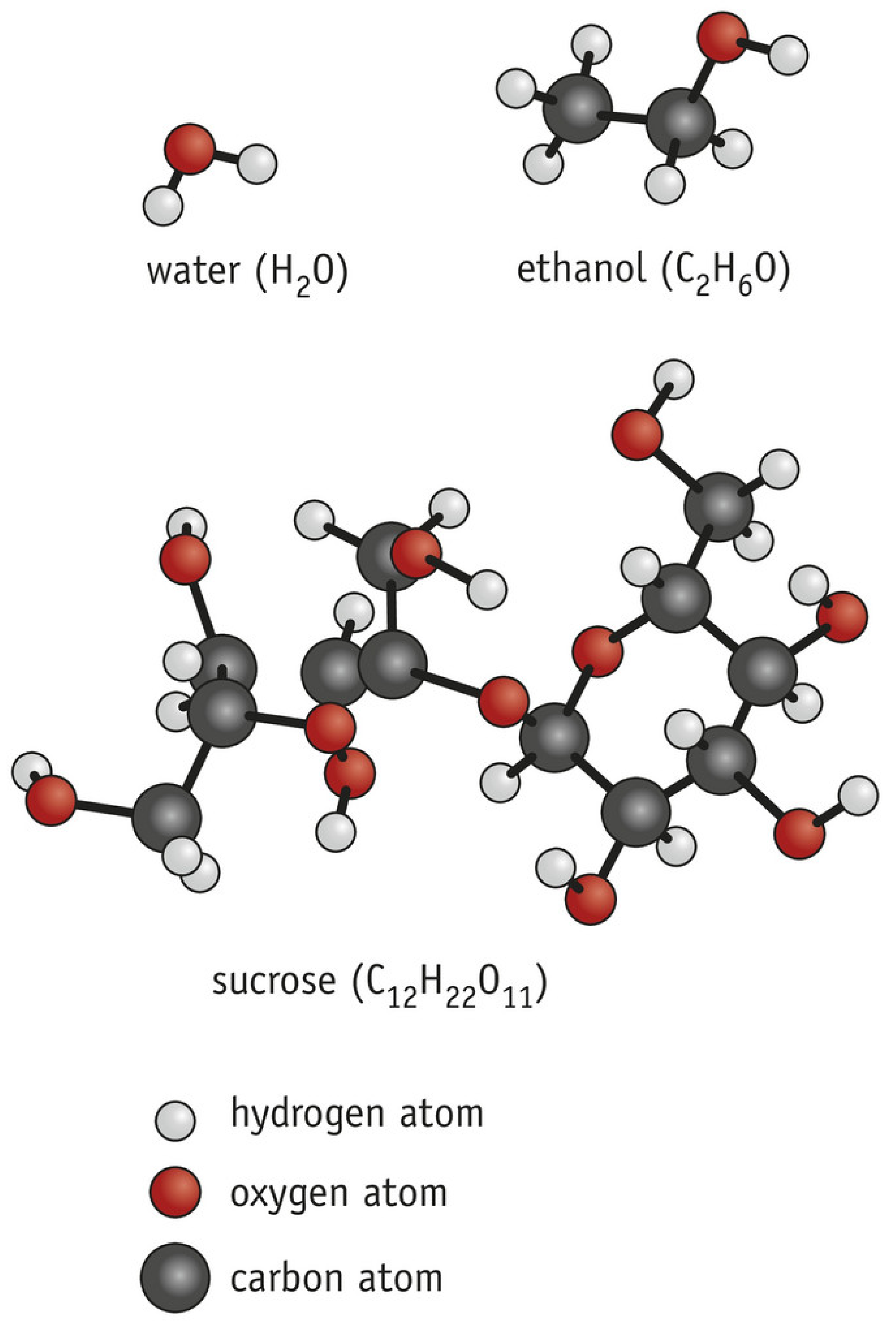
Plus Wavelength and frequency

11 Calculate the frequency of:
- **a** radio waves with a wavelength of 10 cm.
- **b** infrared radiation with a wavelength of 0.01 cm.
- **c** green light with a wavelength of 500 nm.
- **d** X-radiation with a wavelength of 1 nm.

***12** Miriam is reading the website of Radio Rijnmond: "Our transmissions have been on 93.4 MHz since 1 July."
- **a** Calculate the wavelength of the radio waves.
- **b** Is Radio Rijnmond an AM broadcaster or an FM broadcaster? Explain.
- **c** Radio broadcasting distinguishes between long wave, medium wave and short wave transmissions.
  Determine using figure 4 on page 263 which type of wave Radio Rijnmond uses for its transmissions.

2 Atoms

There are huge numbers of pure substances – many millions. There are therefore also millions of different molecules. Chemists have discovered that all those molecules are made up of a little over a hundred different building blocks. These building blocks are called atoms.



▲ **figure 12**
three models of molecules

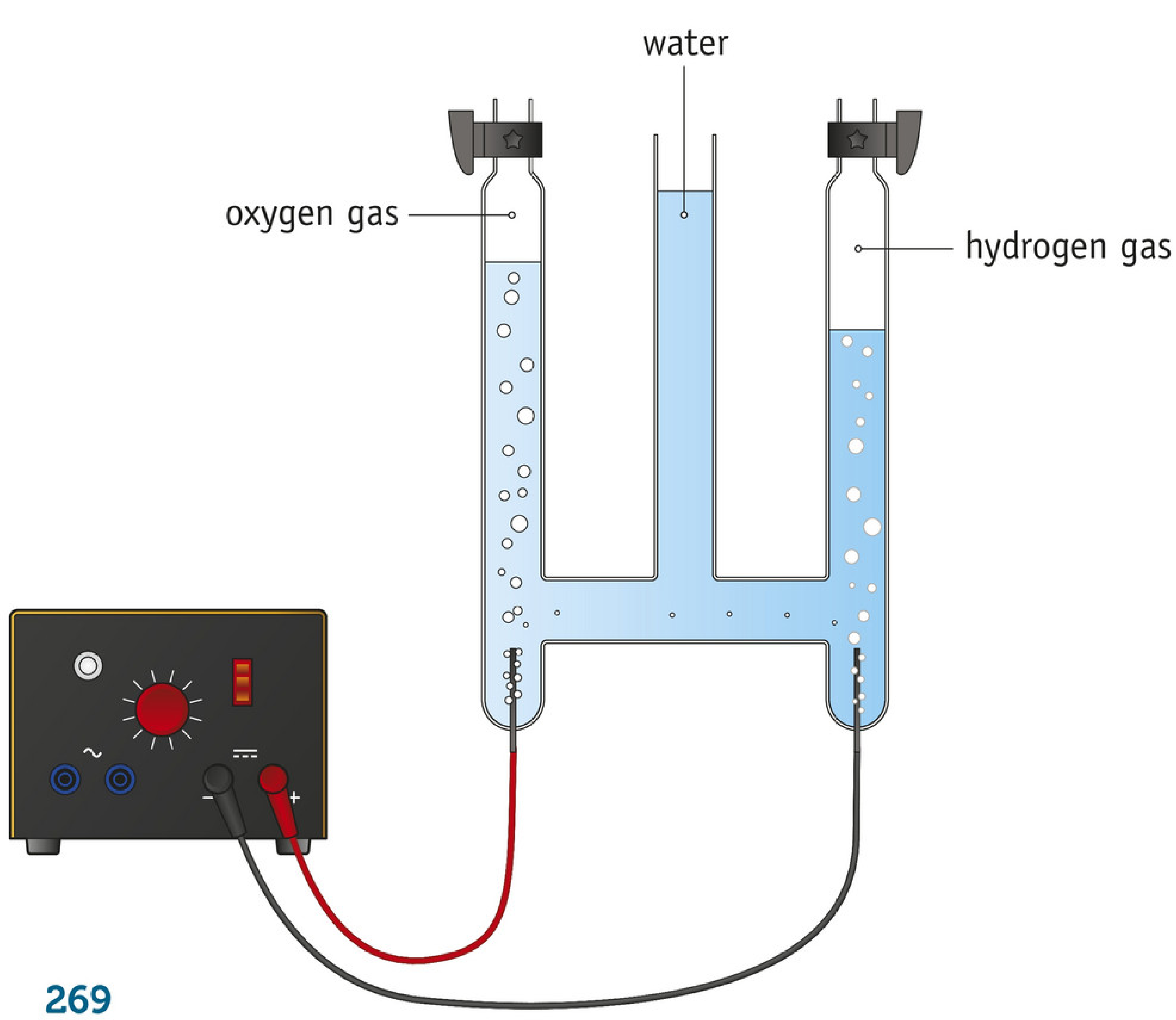
Molecules and atoms

Water is made up of water molecules. Figure 12 shows a model of a water molecule. Experiments have shown that water molecules can be split (broken down) further into even smaller particles: **atoms**. Every water molecule consists of three atoms, one oxygen atom and two hydrogen atoms.

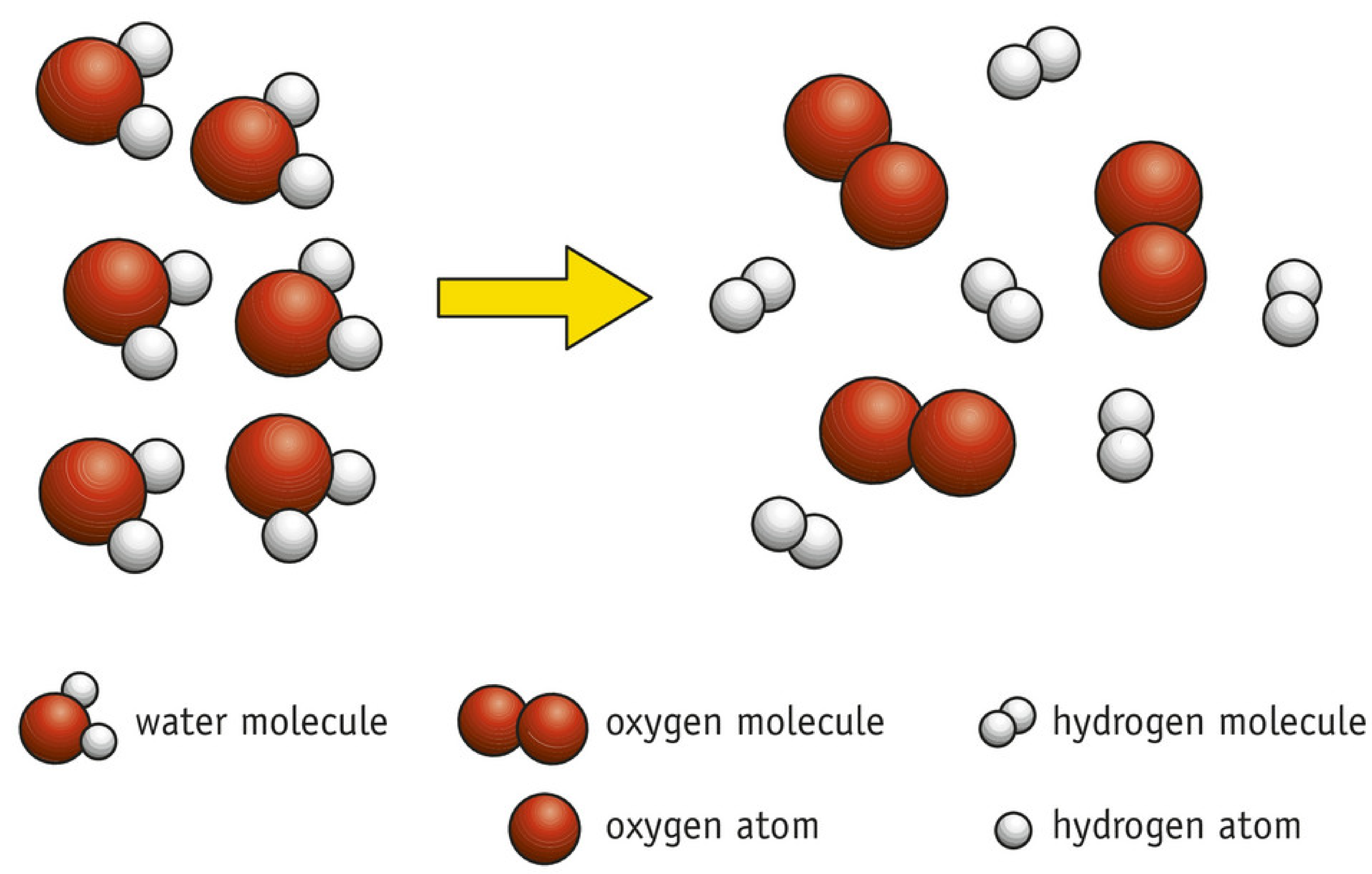
Water molecules are relatively small. The molecules of ethanol (the alcohol in wine and beer) and sucrose (granulated sugar) are clearly larger, as is shown in figure 12. An ethanol molecule has nine atoms and a sucrose molecule has as many as 45. Even so, you will only find three different types of building blocks in these molecules, carbon atoms, hydrogen atoms and oxygen atoms.

Breaking substances down

There are various ways to break substances down. For instance you can break water molecules down using electricity in the Hoffman apparatus (figure 13). If you pass a current through water, water molecules will be broken down continuously. Two new substances are generated instead, the gases hydrogen and oxygen.



▶ **figure 13**
breaking water down with the Hoffman apparatus



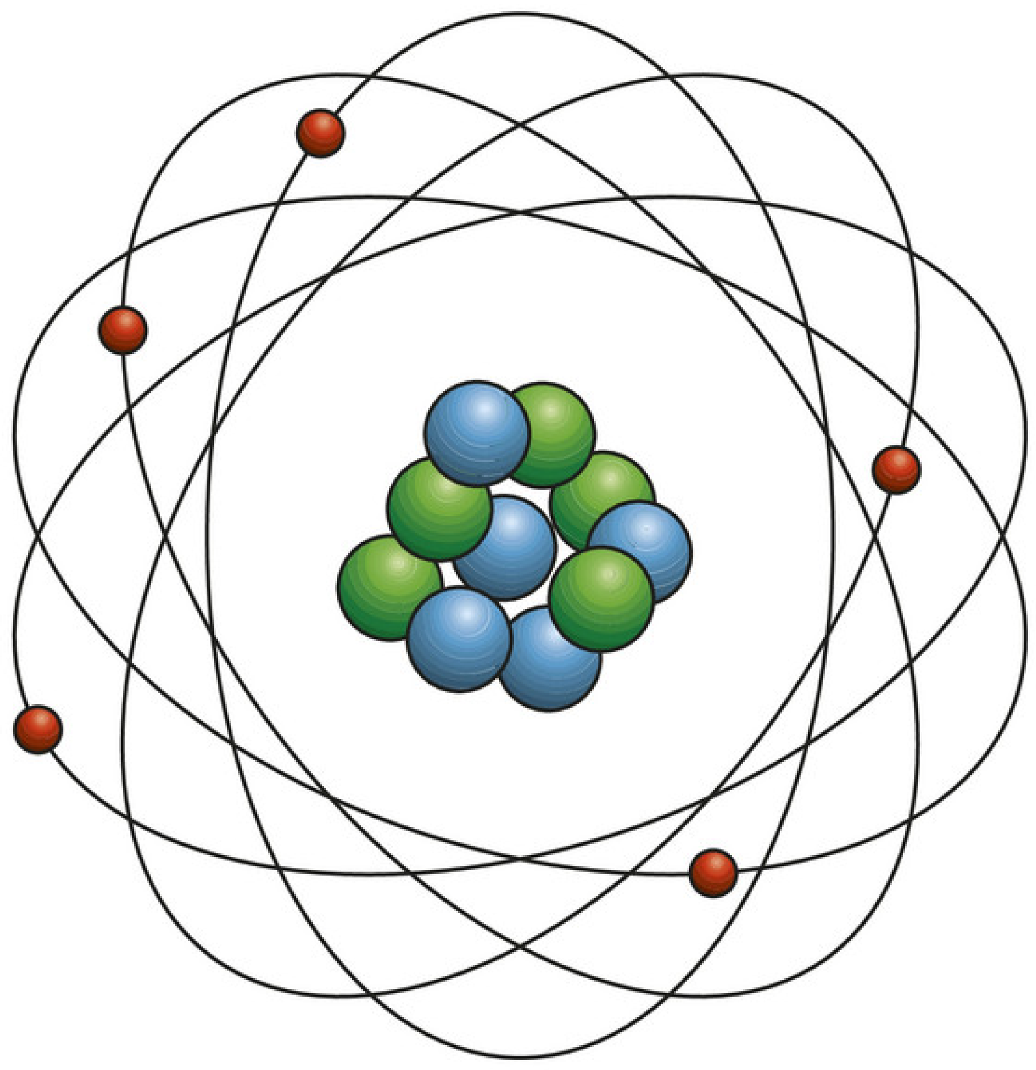
▶ **figure 14**
When you break water down, you get hydrogen and oxygen.

The drawing in figure 14 shows you what happens to the molecules when water is broken down. You can see that the water molecules are pulled apart. After that, the loose building blocks form new combinations. Hydrogen molecules (made up of two atoms of hydrogen) and oxygen molecules (made up of two atoms of oxygen) are generated.

Hydrogen and oxygen are called **elements**. An element is a substance that cannot be broken down any further. This is because an element only consists of one type of atom. Oxygen only contains oxygen atoms, hydrogen only has hydrogen atoms. Because there are a little over one hundred different types of atoms, there are also just over a hundred different elements (table 3).

▼ **table 3** data of a few of the elements

element name	symbol	atomic number	state at 20 °C	its pure form is
hydrogen	H	1	gas	colourless and odourless gas
carbon	C	6	solid	diamond, graphite
nitrogen	N	7	gas	colourless and odourless gas
oxygen	O	8	gas	colourless and odourless gas
aluminium	Al	13	solid	light grey metal
chlorine	Cl	17	gas	greenish-yellow gas with an irritating smell
iodine	I	53	solid	purple crystals
platinum	Pt	78	solid	greyish-white metal
gold	Au	79	solid	yellow metal
mercury	Hg	80	liquid	silver-white metal
uranium	U	92	solid	grey metal



▲ **figure 15**
a model of a boron atom
(atomic number 5)

The structure of an atom

For a long time, scientists and philosophers thought that atoms were the smallest particles that exist. The word 'atom' also shows this, it comes from the Greek word *atomos* which means 'indivisible' ('cannot be cut'). But around 1890, physicists discovered that atoms consist of even smaller particles: **protons**, **neutrons** and **electrons**.

Figure 15 shows a simplified representation of an atom of the element boron. Like all atoms, it consists of a nucleus with a number of electrons around it. In reality, the nucleus is much smaller than the atom itself. The atom in figure 15 has therefore not been drawn to scale. You could not even see the nucleus in a scale drawing!

The atomic nucleus is made up of two types of particles, protons and neutrons. There is one exception to this rule, the nucleus of a hydrogen atom (the smallest atom there is) consists of one proton and no neutrons.

Protons

A proton has an incredibly small mass: $1.67 \cdot 10^{-27}$ kg (that is 1.67 divided by a billion times a billion times a billion). A proton also has a very small positive charge. The protons in an atomic nucleus are held together by **nuclear forces** that are greater than the repulsive electrical forces between the protons.

Neutrons

Together, protons and neutrons form the nucleus of an atom. The mass of a neutron is almost the same as the mass of a proton, but a neutron has no electrical charge (it is neutral). The number of neutrons in an atomic nucleus must not be too large or too small, otherwise the nucleus will be unstable and will fly apart at a given moment (see section 3).

Electrons

An electron is a negatively charged particle. The mass of an electron is $9.11 \cdot 10^{-31}$ kg, about 1800 times smaller than the mass of a proton or a neutron. The charge on an electron is the same as the charge on a proton, but it has the opposite sign. Two (negatively charged) electrons repel each other equally strongly as two (positively charged) protons.

An atom has as many protons as electrons. That is why an atom is electrically neutral as a whole: you can 'offset' the positive charges on the protons against the negative charges on the electrons.

Isotopes

All the atoms of an element have the same number of protons in their nucleus. Every carbon atom has six protons, every oxygen atom has eight, and so forth. The number of protons therefore determines which element it is. That is why each element has an **atomic number** that is the same as the number of protons in the nucleus. The atomic number of carbon is therefore 6, the atomic number of oxygen is 8, and so forth.

▲ figure 16
Copper is a mixture of two isotopes: 69% of the atoms are copper-63 and 31% are copper-65.

The atoms of one element can have different numbers of neutrons in their nuclei. We then say that the element has different **isotopes**. For instance, the element copper (figure 16) has the isotopes copper-63 (29 protons and 34 neutrons) and copper-65 (29 protons and 36 neutrons). In chemical terms, there is no difference between these isotopes, they look just the same and react in the same with other substances.

The numbers 63 and 65, which are used to distinguish the isotopes of copper from each other, are called **mass numbers**. The mass number indicates the total number of nuclear particles: the number of protons + the number of neutrons. Because the mass of the electrons is so small it can be ignored, the mass number is also a measure of the overall atomic mass. A copper-65 atomic nucleus consists of more particles and therefore has a greater mass that a copper-63 nucleus.

Plus The periodic table

The periodic table (figure 17) is a table consisting of rows (the periods) and columns (the groups). All elements are ordered in a clear way into the boxes in this table, approximately a hundred of them.

The elements are ordered by atomic number (the number of protons in the nucleus), along the rows. For example, the elements with atomic numbers 11 through 18 are in the third row: sodium through to argon.

Elements with similar properties are placed below each other in the table. This results in eighteen groups of elements with similar properties. In group 18 on the far right, you have for example the inert gases: helium (He), neon (Ne), argon (Ar) and so forth. A feature of these gases is that they do not react with other substances. Inert gases are used for filling light bulbs.

▼ figure 17
the periodic table of the elements

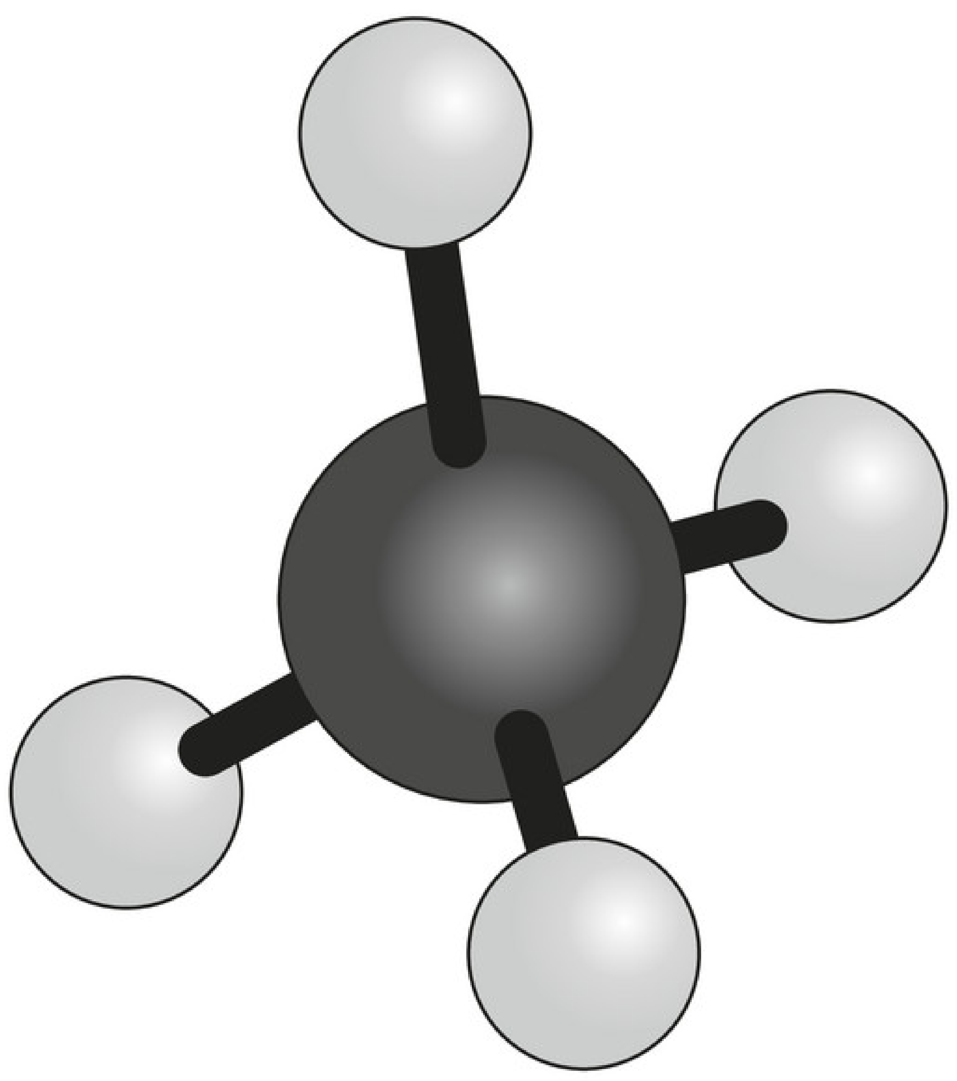
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn

Exercises

13 Answer the questions below.
a Why is oxygen called an element and water is not?
b Which three types of particles make up an atom of copper?
c Which of these particles are in the nucleus of the copper atom?
d When are two atoms isotopes of the same element?

14 Explain what is meant by:
a the atomic number of an element.
b the mass number of an isotope.

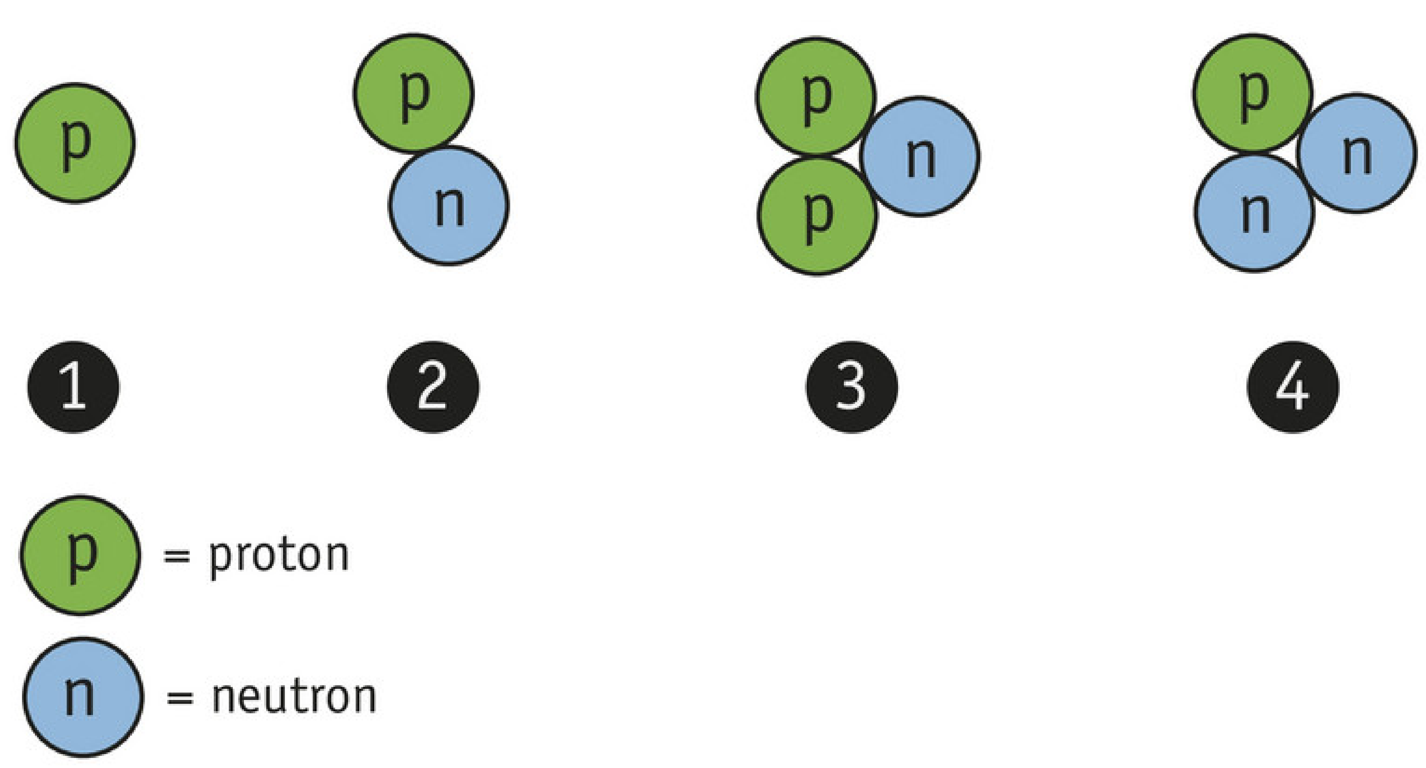
15 The Hoffman apparatus can be used to decompose water. One tube then contains hydrogen gas and the other contains oxygen gas.
Explain why:
a hydrogen and oxygen are generated when water is broken down, and why, for instance, nitrogen and carbon are not.
b twice as many hydrogen molecules as oxygen molecules are generated when water is broken down.



▲ **figure 18**
a model of a methane molecule

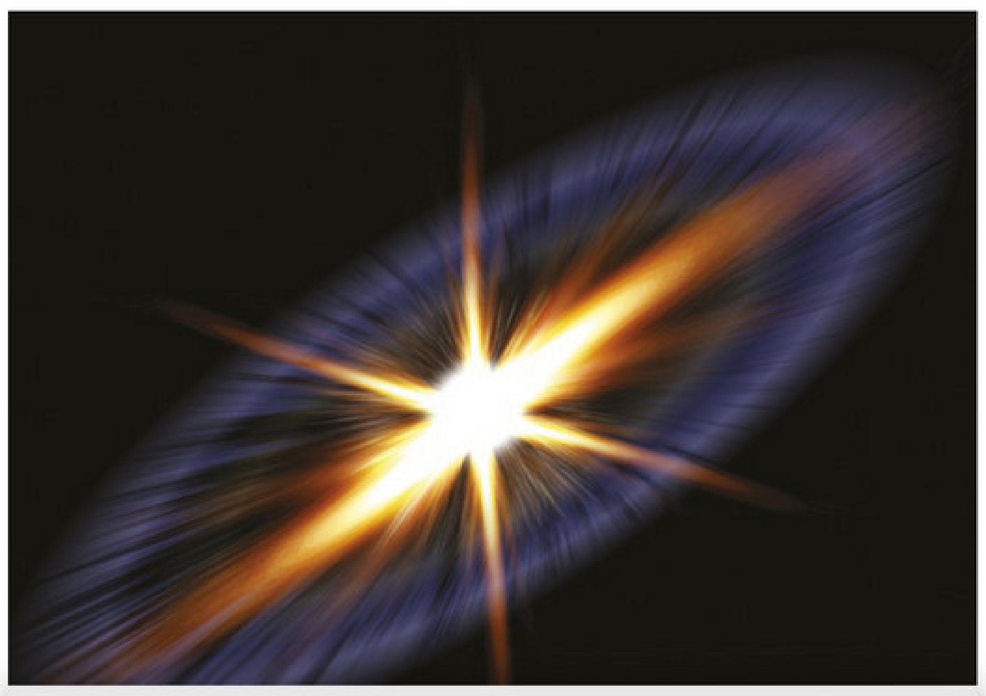
16 Methane (CH_4) is the most important component of natural gas (figure 18).
Which elements are generated when methane is decomposed? Explain.

17 Figure 19 shows a schematic drawing of four atomic nuclei.
Which nuclei are from the same element? How can you tell?



▶ **figure 19**
four atomic nuclei

18 This exercise is about two atoms, X and Y.
a Atom X has 80 protons and 118 neutrons.
– Of which element is it an isotope? See table 3.
– What is the atomic number of this element?
b Atom Y has the same mass number as atom X, but two fewer protons.
– How many neutrons does atom Y have?
– Of which element is it an isotope?
c Do the isotopes from parts a and b have the same chemical properties? Explain.



Neutron stars

When very large stars 'die' and their core collapses, this may create a neutron star. Gravity makes the pressure in the core of such a star so high that the atoms are compressed together: protons and electrons fuse together to make neutrons. Neutron stars have a diameter of approximately 20 kilometres into which all their mass is compressed. The density of the star is so high that a single teaspoonful of matter would weigh a billion tons!

Source: De nieuwe ster

▲ **figure 20**
A neutron star is created after the explosion of a heavy star.

19 Read the text in figure 20, an excerpt from an article.

a Explain why an uncharged particle is generated when a proton and electron fuse.

b The density of a neutron star is, on average $1.0 \cdot 10^{17}$ kg/m^3. Figure 20 contains a statement about the mass of 'a teaspoonful of neutron star'.
Use a calculation to check if this statement could be correct. To do that, first estimate how many cm^3 there are in 'one teaspoonful'.

***20** Geraldine reads the following text in a physics book:

> An atom consists mostly of empty space. Its nucleus is very tiny, even on the scale of the atom. Compared to it, the distance between the nucleus and the electrons is extremely large! If you were to blow up a hydrogen atom to the size of an average hot-air balloon (a diameter of 20 m, for five passengers), the nucleus would be the same size as a grain of sand, with a diameter of 0.35 mm.

Geraldine knows that a hydrogen atom has a radius of approximately 55 pm, where 1 pm = 10^{-12} m.
Use this data to calculate the diameter of the nucleus of the hydrogen atom.

Plus The periodic table

21 The lightest element in group 11 of the periodic table is copper.

a Write down two more elements that you find in this group.

b Write down three properties that these elements share.

22 79% of the magnesium in the Earth's crust is Mg-24, 10% is Mg-25 and 11% is Mg-26.

a Copy table 4 and fill in the missing data.

b Where can you find these three isotopes in the periodic table?

c The word 'isotope' comes form the Greek words *iso* (equal, the same) and *topos* (place, location).
Explain why this name was chosen.

▼ **table 4** three isotopes of magnesium

isotope	atomic number	mass number	number of protons	number of neutrons
Mg-24	12			
	12			13
		26		14

3 Ionising radiation

Infrared radiation is only dangerous if the radiation is very intense, as in an intense fire. It is better for you to stay at a safe distance in that case. X-ray and gamma radiation are different, though. Even small amounts of these forms of radiation are dangerous.

Effects of radiation

When radiation is absorbed, the energy in the radiation will be released. You will notice this if you sit in bright sunlight with a black T-shirt on: you will soon get hot because of the radiation (infrared and light) that falls on your T-shirt. The temperature of your skin rises because the radiant energy is converted into heat. A relatively large amount of energy is needed for this.

Some types of radiation have another effect too. Their radiation energy can break substances down. You will notice this if you leave a sheet of coloured paper in the sunlight for a number of days, for example. The ultraviolet radiation in the sunlight breaks down the dye molecules. As a result, the colours will fade more and more (figure 21). Ultraviolet radiation (UV) can also damage the DNA (the genetic material) in your skin cells.

Radiation that can break molecules down is called **ionising radiation**. Radio waves, infrared (IR) and light are not ionising. UV is slightly ionising, and X-rays and gamma radiation are highly ionising. Even a small amount of X-rays or gamma radiation can harm your health. That is why you must be very careful with these forms of radiation.

▲ **figure 21**
An experiment with UV radiation: the paper has visibly discoloured after two weeks in the Sun.

Radioactive substances

In 1896, the French physicist Henri Becquerel discovered that some substances spontaneously emit ionising radiation (in other words, without any external cause). We now say that such substances are **radioactive**. (The word 'radio' also comes from 'radius', the Latin word for a ray. 'Radioactive' therefore means emitting radiation by itself.)

▲ figure 22
Uranium ore is so radioactive that it is better not to handle it with your bare hands.

You can find radioactive substances everywhere, but mostly in small amounts: in the soil, in water, in the air, in the walls of buildings and even in your own body. A lot of these substances are natural in origin. They are **naturally radioactive** (figure 22). After 1896, people learned how to create new radioactive substances themselves. Such substances are said to be **artificially radioactive**.

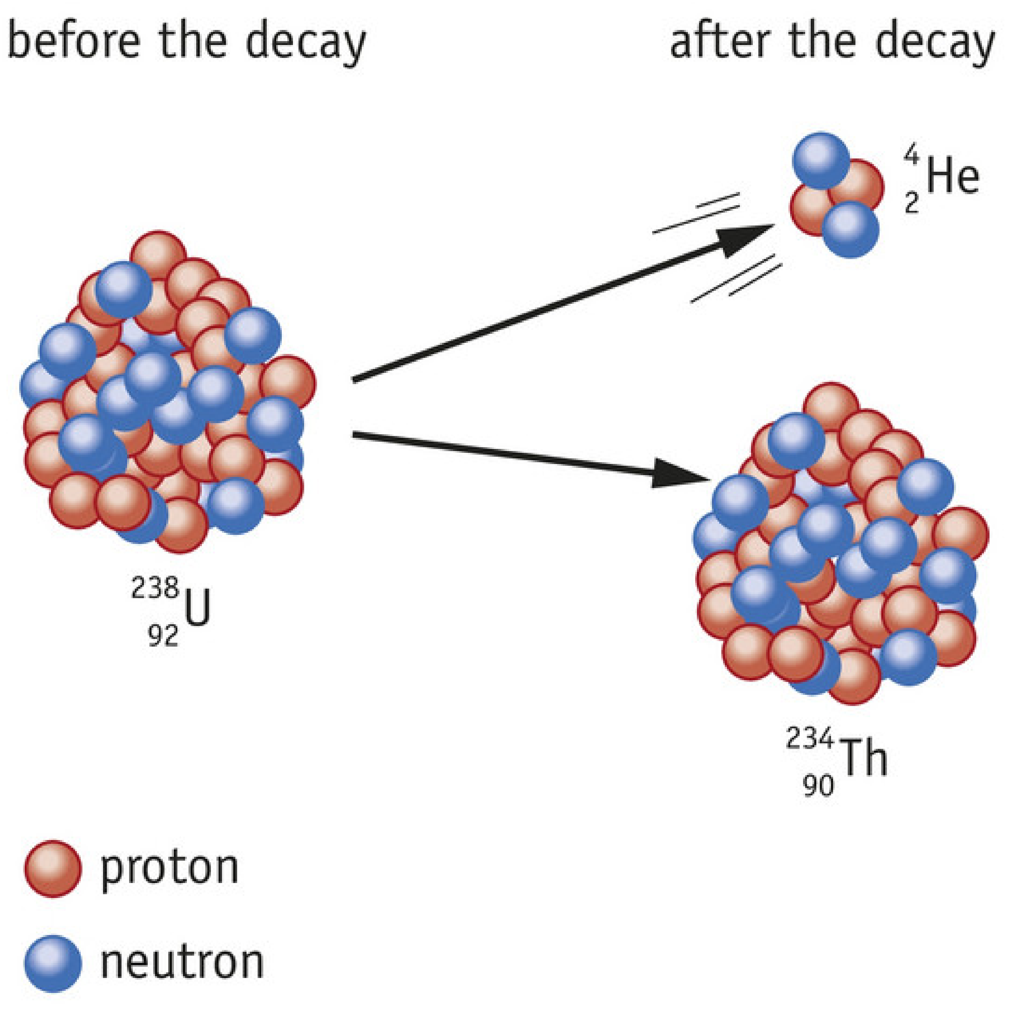
You cannot see, hear or feel the radiation of radioactive substances. You can only observe this radiation using instruments. For example, people who work with radioactive substances must always have a **dosimeter** with them. This registers how much radiation these people have been exposed to (figure 23).

▶ figure 23
a dosimeter

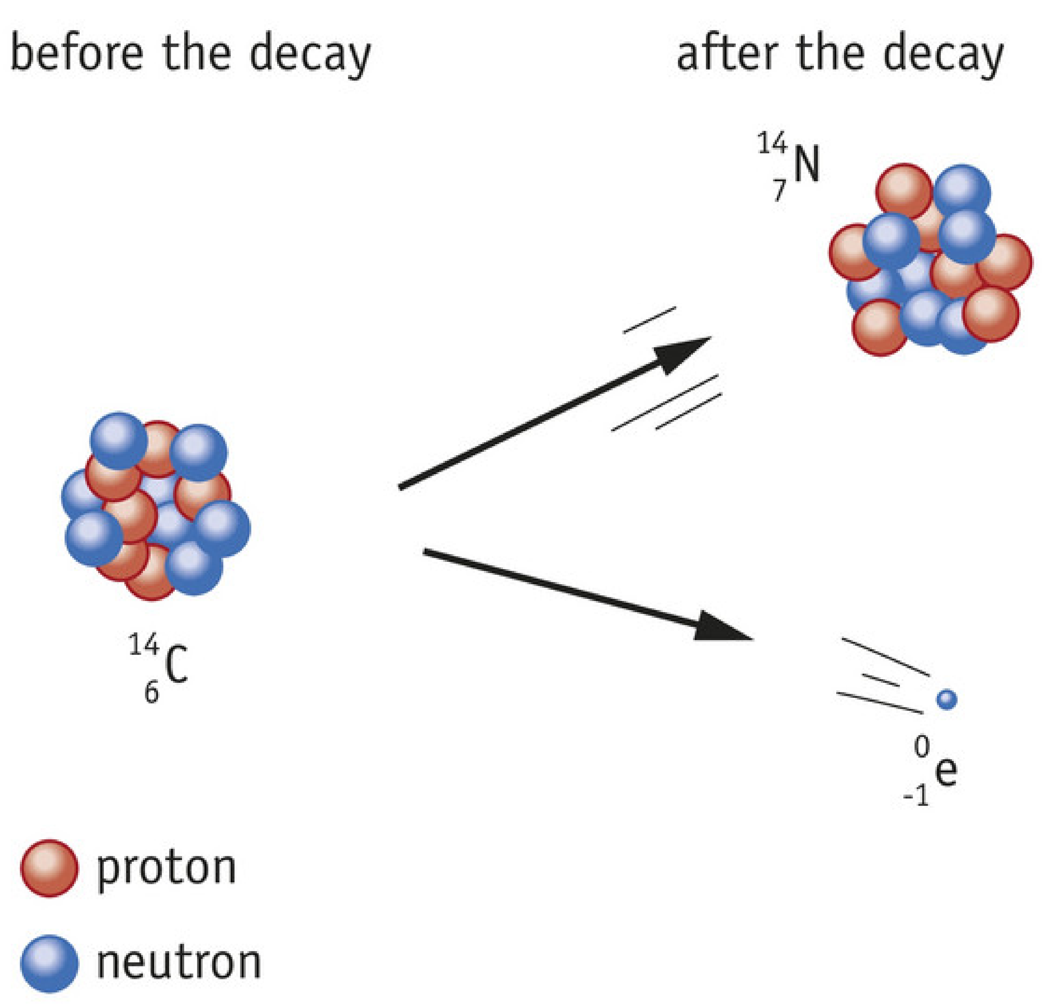
Stable and unstable nuclei

Radioactive substances have atomic nuclei that are **unstable**: the nuclei can change suddenly and emit ionising radiation. You can compare an atomic nucleus like that to a bomb that suddenly goes off without a cause. Most atomic nuclei around you are **stable** and do not change. Otherwise, life on Earth would not be possible.

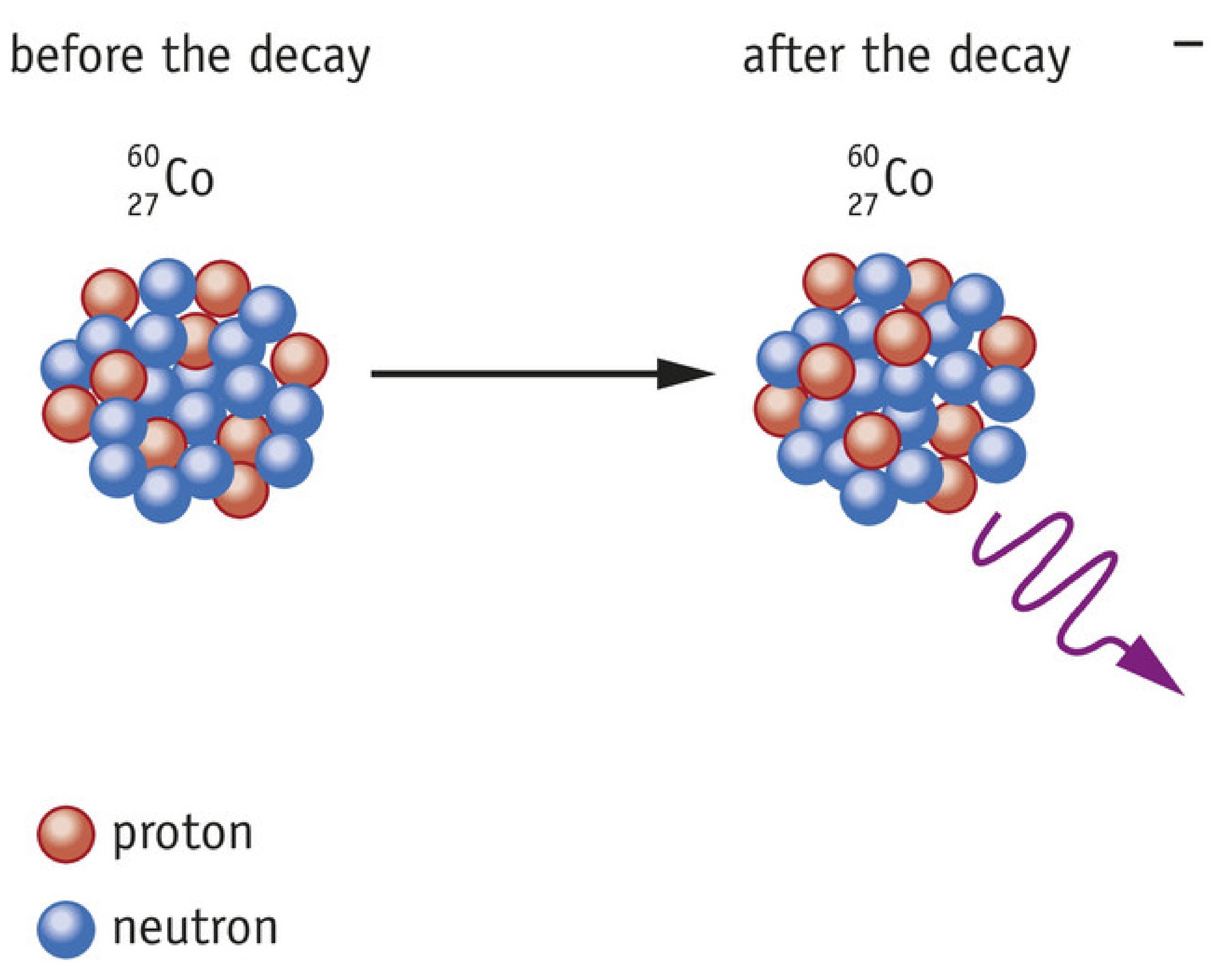
Whether an atomic nucleus is stable or unstable depends on the structure of the atomic nucleus. The circumstances around the atomic nucleus have no effect on it. For instance, it does not matter if the atom is part of a molecule or not. The only thing that affects the stability is the number of protons and neutrons in the atomic nucleus.



▲ figure 24
A uranium isotope emitting an alpha particle.



▲ figure 25
A carbon isotope emitting a beta particle.



▲ figure 26
A cobalt isotope emitting gamma radiation.

Carbon is a good example. There are three types of carbon atoms in nature: carbon-12 or ^{12}C (six protons and six neutrons), carbon-13 or ^{13}C (six protons and seven neutrons) and carbon-14 or ^{14}C (six protons and eight neutrons). The atoms of ^{12}C and ^{13}C are stable, the atoms of ^{14}C are unstable. We say that carbon has three natural **isotopes**: two of these are stable and one is unstable.

A special notation for isotopes is often used when describing radioactivity. In this notation, the mass number and the atomic number are to the left the atomic symbol, with the mass number above and the atomic number below. Carbon-12 is therefore written as $^{12}_{6}C$, carbon-13 as $^{13}_{6}C$, and so forth.

Three types of decay

Unstable atomic nuclei can change in various ways. This is called **radioactive decay**. Three important forms of radioactive decay are stated below:

- **alpha decay** (α-decay)
  In alpha decay, an **alpha particle** is emitted by the nucleus. This particle is the same as a helium nucleus: two neutrons and two protons (figure 24). The mass number of the atomic nucleus therefore decreases by four and the atomic number by two.
  Example: $^{238}_{92}U \rightarrow\ ^{234}_{90}Th +\ ^{4}_{2}He$

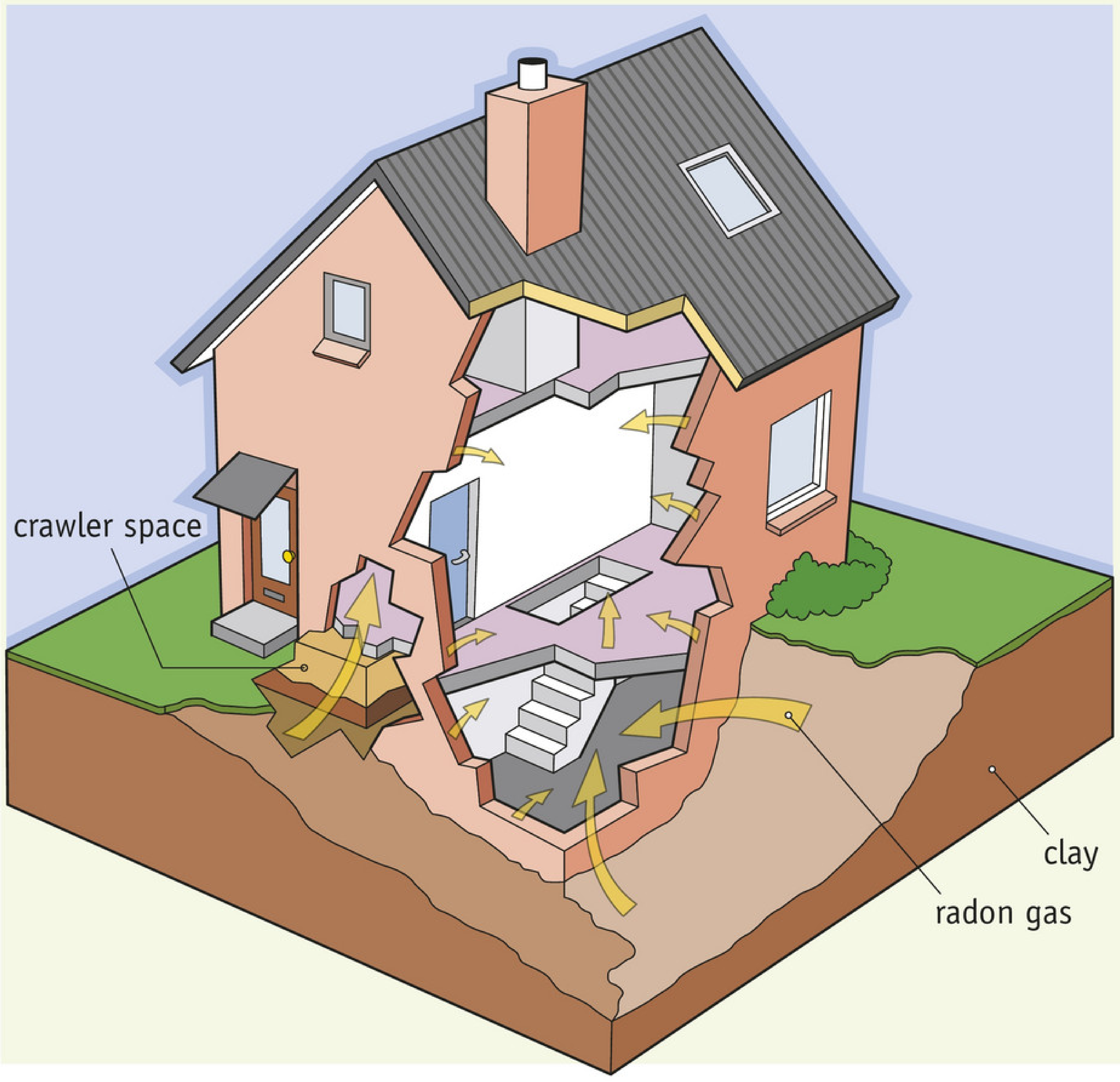
- **beta decay** (β-decay)
  In beta decay, a neutron in the atomic nucleus spontaneously changes into a proton and an electron. The electron is then immediately ejected from the nucleus (figure 25). It is then called a **beta particle**. The mass number of the atomic nucleus does not change, because the number of nuclear particles stays the same. The atomic number increases by one, though, because there is now one more proton.
  Example: $^{14}_{6}C \rightarrow\ ^{14}_{7}N +\ ^{0}_{-1}e$

- **gamma decay** (γ-decay)
  Gamma decay often occurs after alpha or beta decay. There is a lot of internal movement inside the nucleus and it has to lose a lot of energy. It does this by emitting gamma radiation (figure 26). When it does that, the mass number and the atomic number do not change.

Plus Radioactivity around you

Radioactive substances are everywhere, even in your own body. These are almost always in small amounts. Every substance has been investigated to see how much radiation it emits and what health risks this brings.

▼ **figure 27**
You can keep radon gas levels in your home low by ventilating it well.



Radon-222 (Rn-222) is the most harmful of the naturally radioactive substances. Radon is an inert gas that is formed by the radioactive decay of radium in the soil and in building materials, such as bricks and plaster. Some types of ground release more radon than others: for instance, clay gives off 2× as much as sand.

Because radon is a gas, it can then escape from building materials. Radon-222 levels can therefore be much higher in the home than outside. Radon from the soil also accumulates in the crawler spaces under the house. If there is not enough ventilation, radon will stay in the house (figure 27). This can become a risk to its residents.

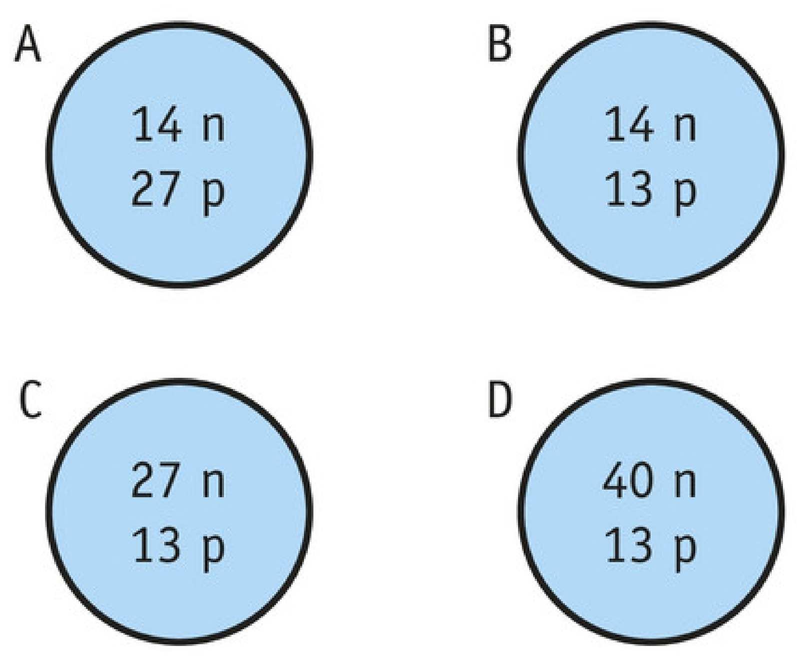
Exercises

23 Answer the questions below.
- **a** What type of electromagnetic radiation has a slightly ionising effect?
- **b** What is the difference between natural and artificial radioactive substances?
- **c** Why must some employees always have a dosimeter with them?
- **d** What makes the nucleus of an atom stable or unstable?
- **e** How does an atomic nucleus change when it ejects an alpha particle (alpha decay)?

24 The element carbon is found in different forms in nature.
- **a** What is the term for the various forms of an element, such as ^{12}C and ^{13}C?
- **b** What is the number 12 in ^{12}C called? What does this number tell you about the atom?
- **c** What is the atomic number of carbon? What does this number tell you about the atom?
- **d** ^{12}C atoms and ^{13}C atoms are both stable. What does this mean?

25 Which form of radioactive decay:
- **a** does not change the mass number or the atomic number?
- **b** increases the atomic number by 1, while the mass number stays the same?
- **c** decreases the mass number by 4, while the atomic number decreases by 2?

26 You can borrow artworks such as drawings and paintings from the Kunstuitleen. The conditions of borrowing state that you cannot just hang the artworks any where on the wall. “Try to avoid daylight as much as possible (with vertical blinds, roller blinds, drapes, shutters and adhesive foil). Otherwise colours may fade significantly.”
- **a** What is meant by ‘fading’ of the colours?
- **b** Which type of radiation causes this change of colour?



p = proton
n = neutron

▲ **figure 28**
Which drawing is correct?

27 Which drawing in figure 28 shows a $^{27}_{13}\text{Al}$ nucleus?

28 Explain what type of radiation is emitted:
- **a** when lead-204 decays, without changing into another isotope.
- **b** when nickel-63 changes into copper-63 because of radioactive decay.
- **c** when radium-224 changes into radon-220 because of radioactive decay.

29 Search the Internet for information about the chemical element radium.
- **a** How many stable isotopes does radium have? And how many unstable isotopes?
- **b** Is radium also found in nature or are all its isotopes artificial?
- **c** What is the number of protons and neutrons in a radium-226 nucleus?
- **d** What type of atom is generated in the radioactive decay of radium-228?

30 The isotopes that are generated by radioactive decay can also be radioactive. Sometimes there is a whole chain of radioactive isotopes which follow each other one by one until the final decay reaction gives a stable atomic nucleus.
Figure 29 shows you six steps in the decay chain of uranium-238 as it decays into (stable) lead-206. Some data has been left out in these steps. Write down what is still missing:
- **a** in step 2.
- **b** in step 3.
- **c** in step 12.
- **d** in step 13.
- **e** in step 14.

Step 1 $^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$
Step 2 $^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + \ldots$
Step 3 $\ldots \rightarrow {}^{234}_{92}\text{U} + {}^{0}_{-1}\text{e}$
(…)
Step 12 $^{210}_{82}\text{Pb} \rightarrow {}^{\ldots}_{83}\text{Bi} + {}^{0}_{-1}\text{e}$
Step 13 $^{\ldots}_{83}\text{Bi} \rightarrow {}^{210}_{\ldots}\text{Po} + {}^{0}_{-1}\text{e}$
Step 14 $^{210}_{\ldots}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + \ldots$

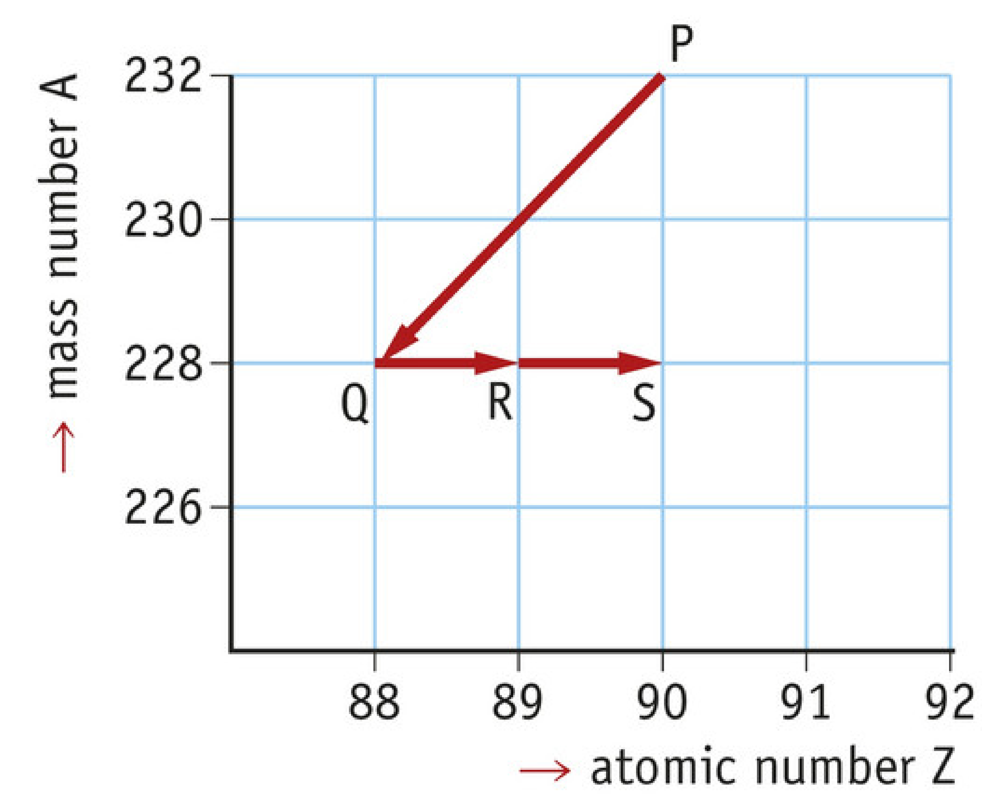
◀ **figure 29**
the decay chain of uranium-238

***31** Radioactive decay can be described with a decay equation.
On page 277 you will find examples of these.
Give the decay equation for:
a plutonium-240 (atomic number 94) changing into uranium by alpha decay.
b nickel-63 (atomic number 28) changing into copper (atomic number 29).

***32** Read the text in figure 30. It is a fragment from a textbook.
Explain:
a what particle is emitted in the decay from P to Q.
b what particle is emitted in the decay from Q to R.
c which two nuclei of the series P, Q, R and S are isotopes.

The (A,Z) diagram

Successive decay reactions of radioactive isotopes can be shown effectively in an (A,Z) diagram. An (A,Z) diagram plots the number of nuclear particles (A) of an isotope against the number of protons (Z). A decay process is shown by arrows in the diagram. This diagram shows you that an unstable nucleus P decays into nucleus Q, after which Q decays into nucleus R. Finally, R decays into the stable nucleus S.



▲ **figure 30**
an (A,Z) diagram

Plus Radioactivity around you

33 Radon-222 is generated as a result of the decay of radium-226.
a What type of radiation is emitted in this type of decay?
b In the home, radon-222 levels can be much higher than outdoors. Give two causes for this.
c Radon-222 can cause lung cancer if it gets into the lungs. Explain how radon-222 from the ground can end up in someone's lungs.

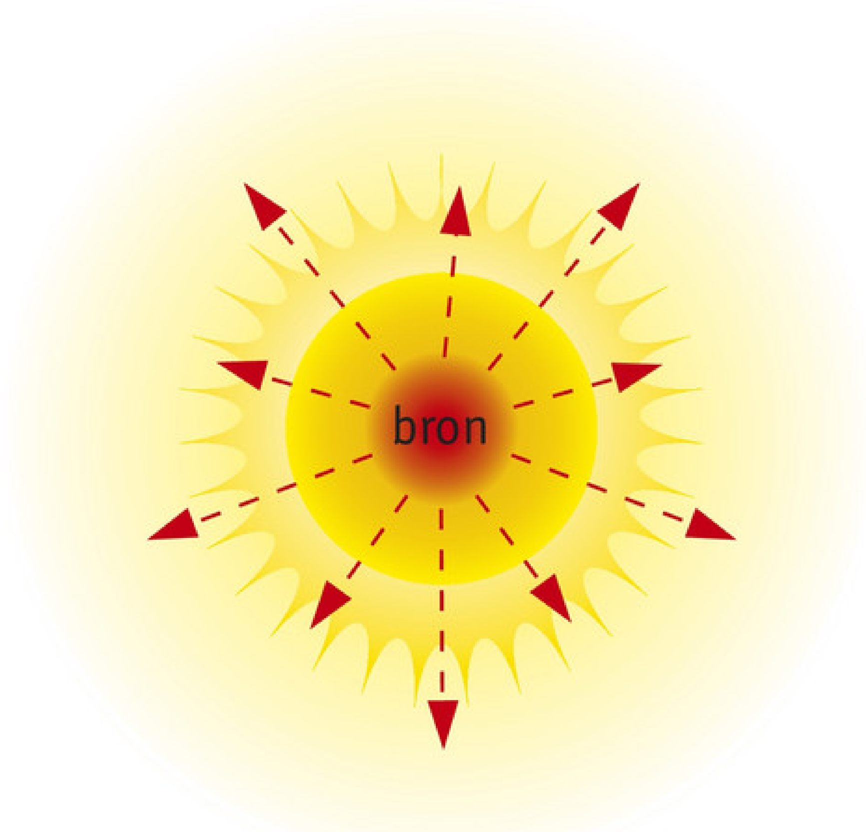
***34** What is better if you want to keep the amount of radon-222 in your home as low as possible:
a A wooden house or a house made of bricks?
b A draughty house or a house with hardly any ventilation?
c A house on the Veluwe or a house in the Betuwe?
Tip: look in your atlas.

4 Protection against radiation

The ionising radiation emitted by radioactive substances can cause damage inside your body. High doses of radiation can even be life-threatening. That is why there are rigid safety regulations for working with radioactive substances.

Penetrating power

A radioactive substance is a source of particles and electromagnetic waves. The particles and waves move in all directions, away from the source. Physicists use the word radiation for 'something' that moves away from the source (figure 31). That is why the particles and the waves are both called radiation, although they are totally different in all other aspects.

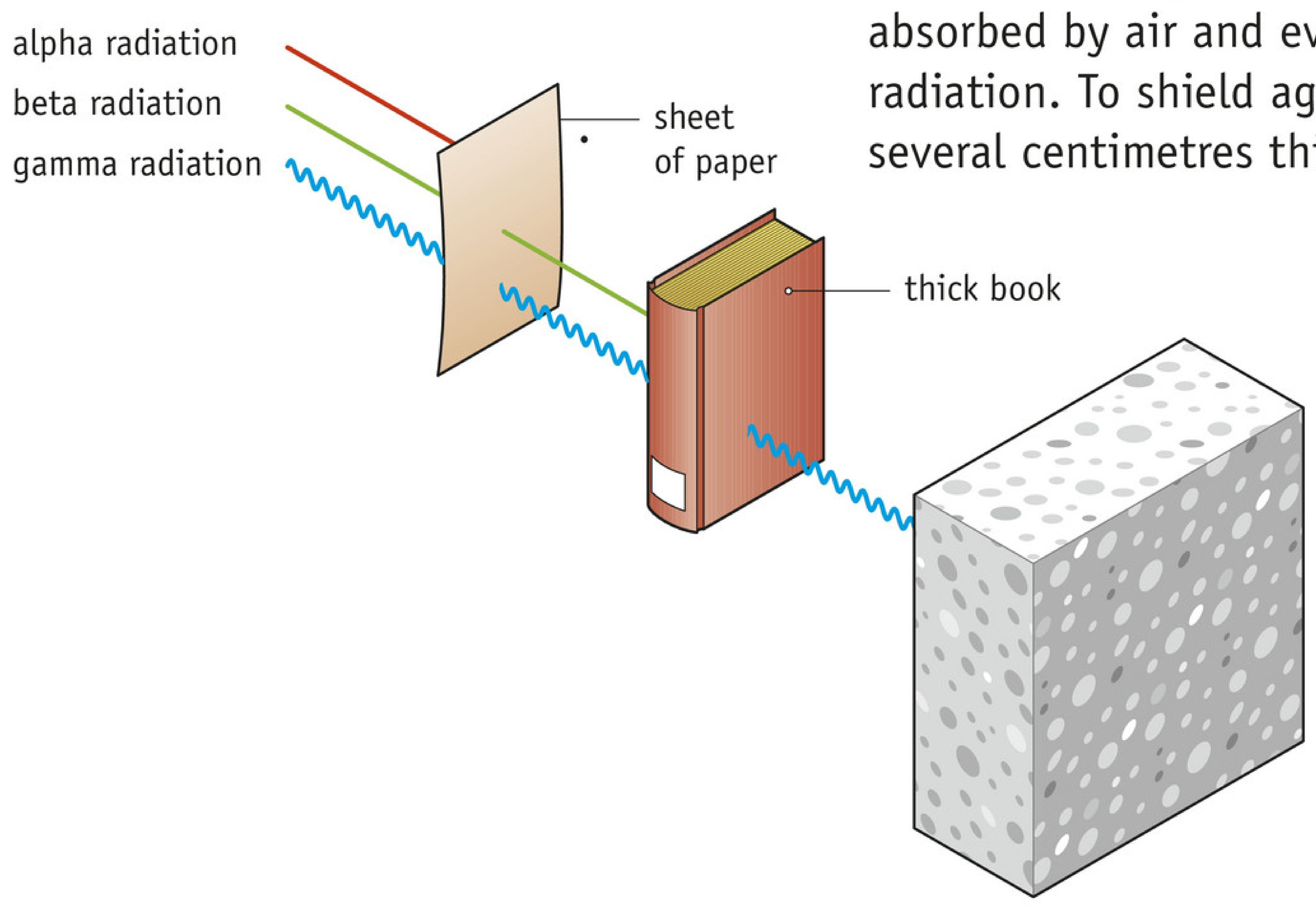


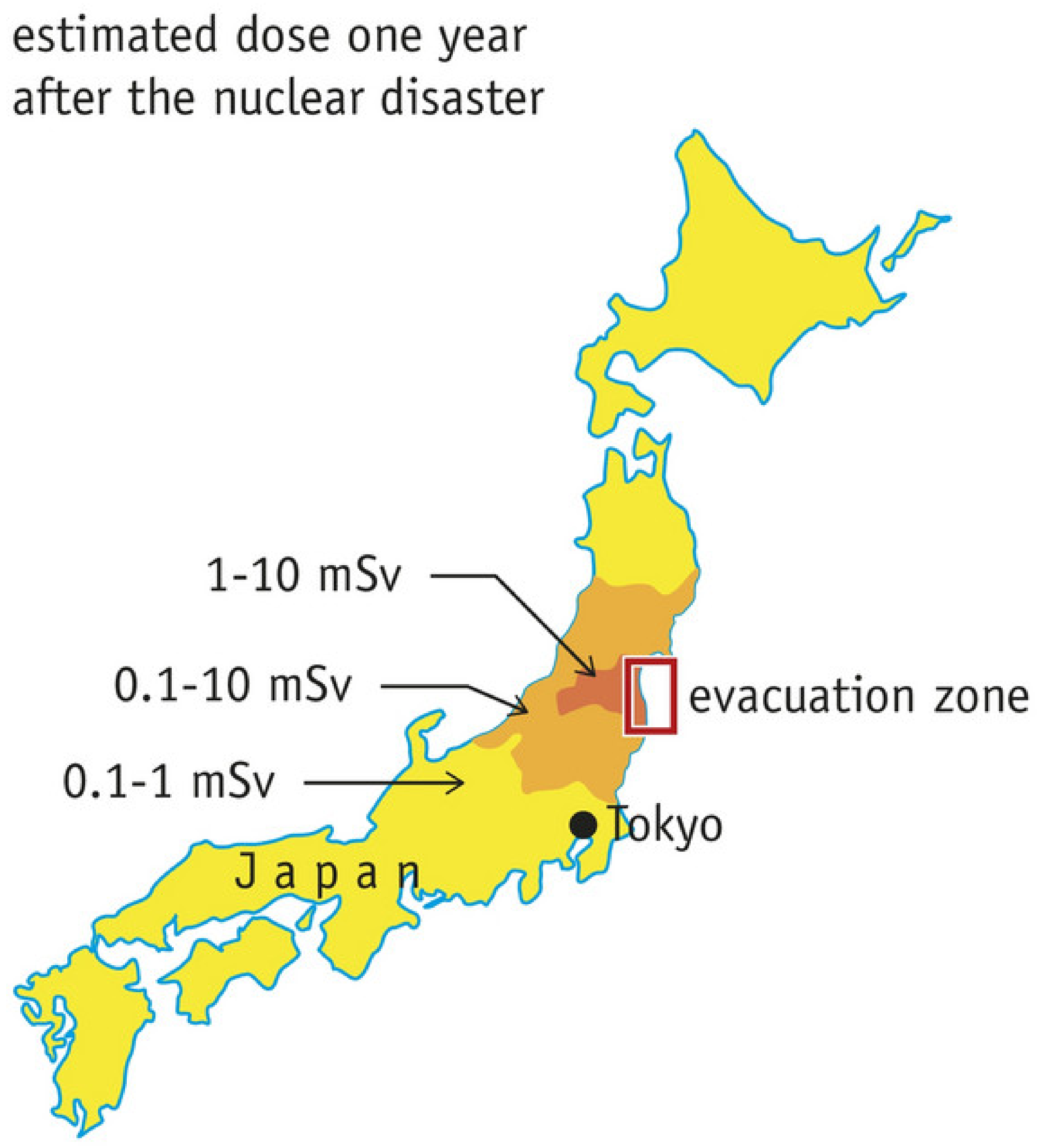
▲ **figure 31**
You could draw this image for any type of radiation.

You can see that the various types of radiation are totally different from each other, when you look at their **penetrating power**. One type of radiation can penetrate substances much more deeply than another type of radiation (figure 32).

- The **alpha radiation** (or α-radiation) generated in alpha decay cannot penetrate deeply into substances. Because an alpha particle is relatively large, it quickly loses all its energy when it collides with atoms. A sheet of paper, a few centimetres of air or the dead outer layer of your skin are sufficient to stop alpha particles.
- **Beta radiation** (β-radiation) clearly penetrates further than alpha radiation. Beta particles are much smaller than alpha particles and can therefore penetrate more deeply into substances. They can penetrate air a few tens of centimetres. However, beta particles are usually stopped by a 4 mm thick plate of aluminium or a thin glass plate.
- **Gamma radiation** (γ-radiation) consists of waves that propagate at the speed of light. These waves are very penetrating. They are hardly absorbed by air and even a metal plate stops only little gamma radiation. To shield against gamma radiation, you need a layer of lead several centimetres thick, or an even thicker layer of concrete.

▼ **figure 32**
the penetrating power of three types of radiation





▲ **figure 33**
Amounts of radiation after the nuclear disaster in Fukushima were stated in sieverts.

Dangers of radiation

Alpha, beta and gamma radiation are all highly ionising. They can break down molecules by 'knocking' electrons out from the molecule. The forces that are keeping the atoms together then disappear and the molecule decomposes. A single alpha particle can do this thousands of times, before it loses its speed (and its energy).

Ionising radiation can make people ill, because it damages the DNA and other important molecules in the cells. How much damage there is, depends on:
- the amount of radiation energy that is absorbed: the greater the amount of energy, the more damage;
- the type of radiation: alpha radiation causes much more damage than beta or gamma radiation for the same amount of absorbed energy.

If employees have been irradiated, the **equivalent dose** that they have been exposed to will be determined (figure 33). This is a measure of the amount of damage caused inside their body by the radiation. The equivalent dose is measured in sieverts (Sv).

A dose of 1 Sv of alpha radiation causes as much damage as a dose of 1 Sv of gamma radiation. We therefore say that these doses are equivalent, even though the actual amount of energy is different. Table 5 shows the health effects of the various doses of radiation.

▼ **table 5** the consequences of radiation for the human body

equivalent dose (mSv)	effect on the body
0-250	no noticeable effects
250-1000	nausea (feeling sick) and loss of appetite; bone marrow and lymph nodes are damaged
1000-3000	severe nausea, loss of appetite, infections, temporary reduction in white blood cell count, severe damage to bone marrow and lymph nodes
3000-6000	bleeding; infections; diarrhea; skin damage; infertility
6000-10,000	damage to the central nervous system; victims die within a few days
> 10,000	loss of consciousness or coma; victims die within a few hours

Protection against radiation

If a radioactive source is not shielded well, ionising radiation can reach your body from the outside. This is called (external) **irradiation**. Because your body does not come into contact with the radioactive substances, you will not become radioactive. But the cells in your body can be damaged.

▲ figure 34
A container for transporting radioactive substances. The inner and outer walls are made of steel. Between them is a thick layer of lead.

Gamma radiation is by far the most dangerous for irradiation. Alpha particles can only travel a few centimetres through air and often do not even reach your body. The fastest beta particles can penetrate the skin a few millimetres at most. A layer of plastic of 0.5 cm thick is often enough to stop them. But the penetrating power of gamma radiation – like X-rays – is much greater.

People who work with radioactive sources, must therefore stick to the following rules:

- Make sure that the **distance** from the source is as large as possible. Radiation spreads as it moves away from the source and therefore becomes weaker and weaker.
- Make sure that the **time** for which you are irradiated is as short as possible. The shorter the time, the less radiation energy your body absorbs.
- Use **shielding material** that absorbs the radiation. The greater the density of the material, the more effectively the radiation is shielded. Lead (ρ = 11.3 g/cm^3) is widely used as a shielding material (figure 34).

Preventing contamination

If radioactive substances are released into the environment, they can enter your body through the air that you breathe, the water that you drink and the food that you eat. Radioactive substances can land on your skin. This is called **radioactive contamination**. This not only causes radiation damage to your body, but your body becomes a radioactive source too.

Contamination does not have to happen in one go. Radioactive substances can also build up slowly in your organs. For instance, radioactive iodine accumulates in the thyroid, just like normal iodine. Calcium, strontium and radium build up in the bones. Radium, for example, can enter your body in your food (figure 35).

▲ figure 35
Brazil nuts contain a relatively large amount of radioactive radium.

The purpose of a lot of safety rules for radioactivity is to prevent contamination. For example, you must not eat, drink or smoke near radioactive sources, and you must always wash your hands after you have worked with radioactive substances. If you get contaminated, you have to take off your contaminated clothes and take a shower. This lets you rinse the radioactive substances off your skin and out of your hair (figure 36).

◀ **figure 36**
Radioactive substances are rinsed off the equipment with water.

Plus Radiotherapy

Doctors use ionising radiation to irradiate tumours. This is called **radiotherapy**. This can be done from the outside (external irradiation) or from inside the body (internal irradiation). Cancer cells divide quickly and are therefore much more sensitive to radiation damage than healthy cells.

X-rays and gamma radiation are used for external radiation (figure 37). During the treatment, the radiation is carefully aimed at the tumour, and the radiation source slowly rotates around the body. This keeps the damage to the surrounding healthy tissues to a minimum.

With internal radiation, the radiation source is inside the body. A doctor can use a hollow needle to place a little piece of radioactive material (a 'seed') into the contaminated tissue. The advantage is that the radiation is given off locally. Gamma and beta radiation are both used for internal irradiation.

◀ **figure 37**
A patient being prepared for irradiation.

Exercises

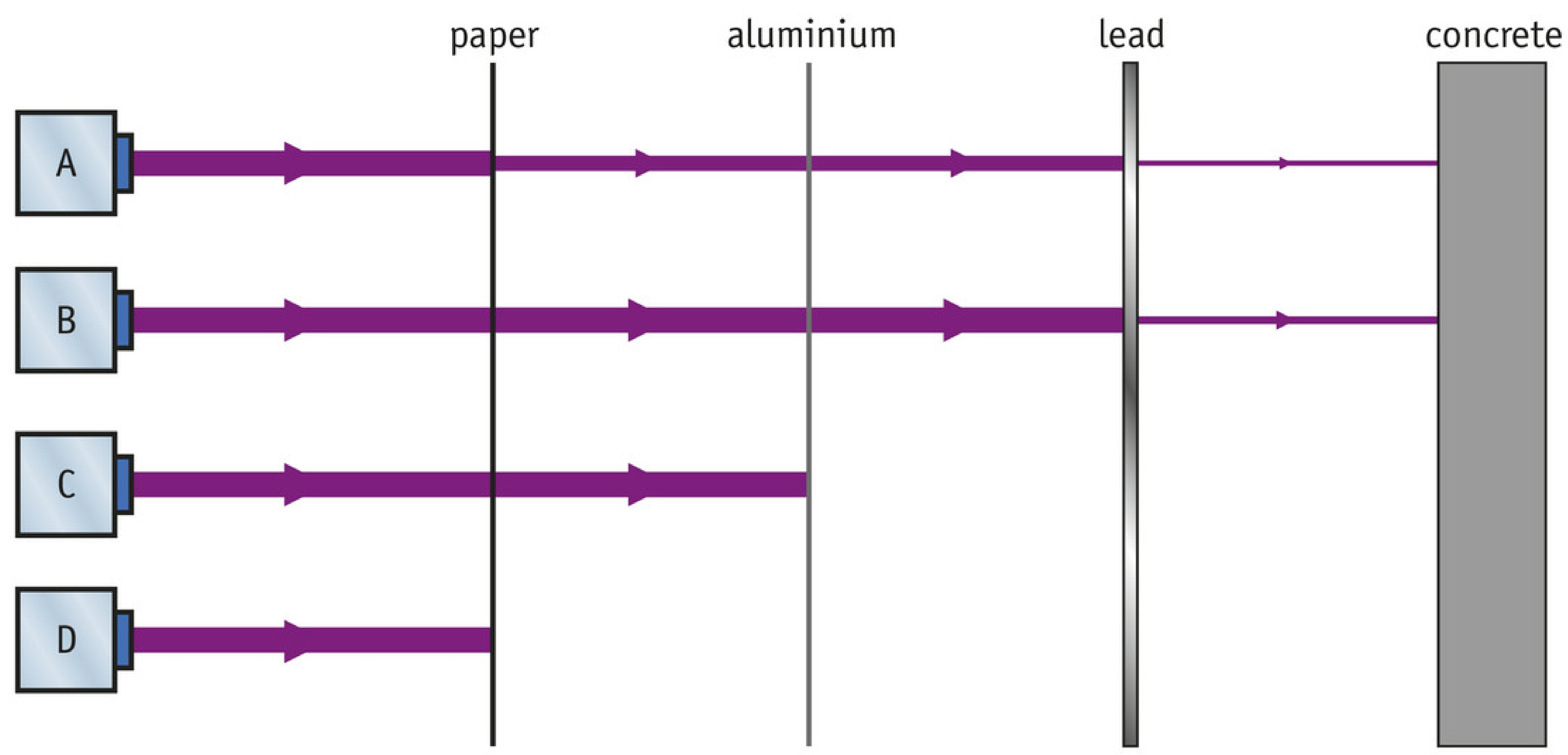
35 Answer the questions below.

- **a** When do physicists call an effect 'radiation'?
- **b** How large is the penetrating power of alpha, beta and gamma radiation?
- **c** What is meant by the 'equivalent dose'? What unit is it measured in?
- **d** What is the difference between irradiation and (radioactive) contamination? Explain.

36 Explain:
a why gamma radiation is more dangerous than alpha or beta radiation when someone is irradiated externally?
b why alpha radiation is more dangerous than beta or gamma radiation if the source is inside the body.
c why lead can be used (and is widely used) to shield radioactive sources of gamma radiation.

37 Write down four ways in which people can get radioactively contaminated.

38 Esther puts four radioactive sources in front of small sheets of different material. Figure 38 shows a schematic drawing of this experiment. The thickness of the arrows is a measure of the amount of radiation. Esther knows that one source emits only alpha radiation, one source beta radiation only, one source gamma radiation only and one source alpha and gamma radiation.
For each source, state which type or types of radiation it is emitting.



▶ **figure 38**
Each type of radiation has a different penetrating power.

39 Figure 39 shows a piece of text from a school book.
a Explain what the writer means by 'an alpha emitter'.
b Alpha emitters can also cause lung cancer.
How can an alpha emitter get into someone's lungs?
c Alpha emitters can easily 'stick' in the lungs.
Explain why this is harmful.

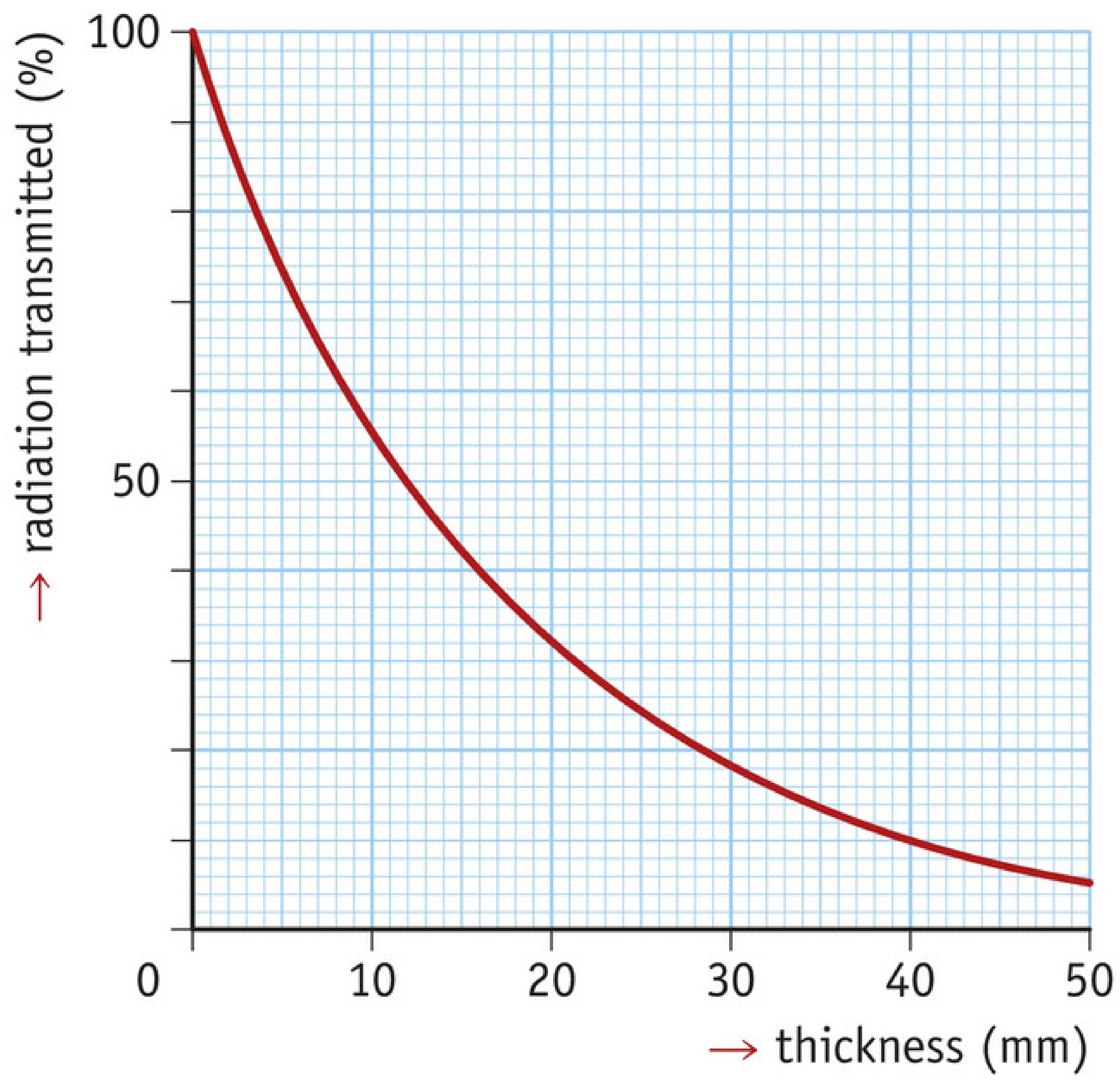
If you compare the penetrating power of the various types of radiation, it turns out that gamma radiation is only eliminated by metres of concrete, that beta radiation is stopped by millimetres of aluminium or centimetres of Perspex, and that alpha radiation can barely even penetrate a sheet of paper or 20 cm of air. Yet alpha radiation turns out to be the most dangerous source of contamination for people. This is caused by the fact that many alpha emitters, when inhaled or eaten, bind chemically in the human body and stay active there for a long time, able to act a very short distance.

▶ **figure 39**
the danger of alpha emitters

40 Lead is used to shield people against gamma radiation.

a Use the graph in figure 40 to calculate how thick the lead shielding must be:
- to absorb 50% of the gamma radiation falling on the body.
- to absorb 90% of the gamma radiation falling on the body.

b A container for transporting radioactive substances has lead walls that are 4.5 cm thick. A radioactive source that emits gamma radiation is put in the container.
Which percentage gamma radiation is stopped by the container?



◀ **figure 40**
The thicker the layer of lead, the more gamma radiation is stopped.

***41** Meat, herbs and products that contain eggs may be contaminated with bacteria such as salmonella. Gamma radiation is often used for export products in order to kill the bacteria.

a Do you think the irradiation will make the products radioactive?

b You can also kill the bacteria by heating the product.
Why is this not an attractive method in these examples?

c What is the disadvantage of trying to kill the bacteria with preservatives (substances to preserve foodstuffs)?

d In a supermarket, you can choose between shrimps that are irradiated, heated or treated with preservatives.
Which shrimps do you choose and why?

42 People who work with radiation sources must stick to all kinds of safety regulations. Figure 41 shows you a few examples.
Which regulation is intended:

a to let you work with radioactive substances as hygienically as possible?

b to shield the radiation as well as possible from your body?

c to make sure that the distance to the radioactive source is as large as possible?

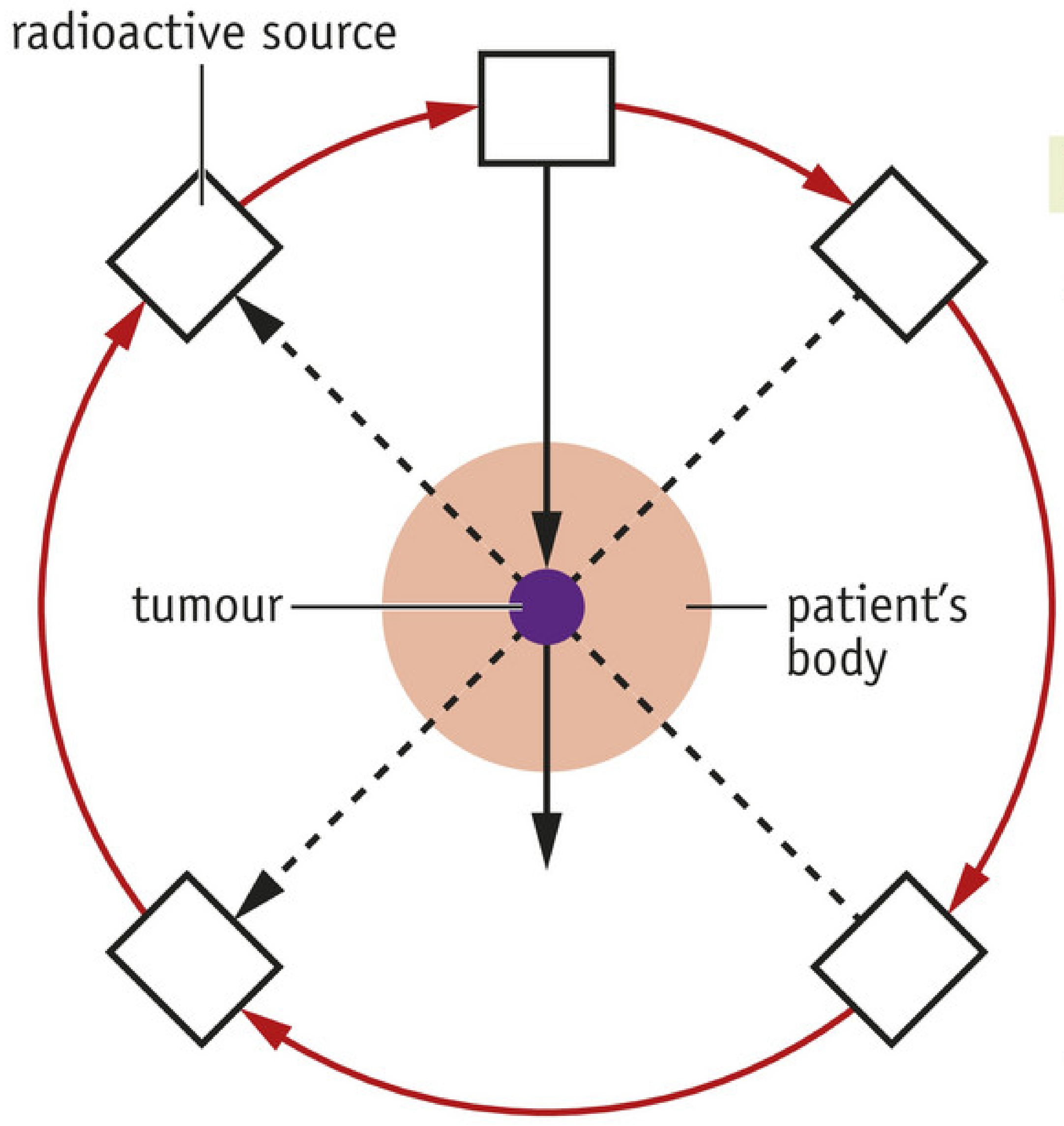
d to make sure that the time that you are exposed to radiation is as short as possible?

1. Do all actions quickly (but precisely).
2. Wash your hands after you have worked with radioactive substances.
3. Do not pick up the radiation source with your hands: use tongs.
4. Wear a lead apron when working with radioactive substances (see photo).

▲ **figure 41**
safety rules for handling radioactive sources

***43** When flying at high altitudes, plane crews are exposed to additional ionising radiation from space. The extra dose must not be higher than 2 mSv a year.

- **a** Explain why this extra dose is believed to be acceptable for airplane crews.
- **b** Everyone in the Netherlands absorbs 2.5 mSv a year from all kinds of sources. A flight from Amsterdam to Tokyo results in an extra dose of 0.075 mSv. By what percentage is your dose increased by a return flight between Amsterdam and Tokyo? Do you think that is a lot?
- **c** The maximum extra dose for pregnant crew members is 1 mSv. Explain why the maximum is lower for pregnant women.
- **d** How often is a pregnant stewardess allowed to make a return flight between Amsterdam and Tokyo?



▲ **figure 42**
A radioactive source is rotated around a patient.

Plus Radiotherapy

44 Figure 42 shows you how a tumour is irradiated. During the treatment, a cobalt-60 source rotates around the patient's body.

- **a** What kind of radiation does cobalt-60 emit, at least? Explain your answer.
- **b** Why does the tumour have to absorb as much radiation as possible?
- **c** Explain why the source moves around the patient in a circle.
- **d** The source is enclosed in a lead housing with one opening. Explain what this opening is used for and where it (therefore) is.

***45** Figure 43 shows you a device that irradiates tumours in the head. The patient's head is in a well-shielded hemisphere in which there are a large number of cobalt-60 sources. The radiation of these sources comes together at one focal point.

- **a** Each source only gives off 0.5% of the total amount of radiation. How many cobalt sources are there in total in the hemisphere?
- **b** What has been done to ensure that the tumour receives as much radiation as possible?
- **c** Why is the patient's head firmly fixed in a metal frame beforehand?
- **d** Give a possible advantage of this system compared to the system where one source rotates around the patient (think it up for yourself).

▶ **figure 43**
A patient is ready for a treatment with a 'gamma knife'.

5 Activity and half-life

▲ figure 44
A researcher holds a Geiger counter close to a radioactive source.

Dozens of radioactive isotopes are used in technology and medical science. The most suitable isotope has to be found for each use. Two factors play an important role in this: the type of radiation that is emitted, and the speed at which the isotope decays.

Measuring the activity

You can detect radioactive sources with a Geiger counter (figure 44). You hear a click each time the device registers an alpha particle, a beta particle or a pulse of gamma radiation. The counter does not distinguish between alpha, beta and gamma radiation, and it does not measure the energy of the particle or photon (individual radiation pulse) either. It only registers the fact that a particle or photon has reached the sensor.

When you have a Geiger counter turned on, it clicks now and then. This is caused by the **background radiation** that is continuously present, there is always some radioactivity in your environment. If the counter suddenly starts to tick faster, there must be a stronger source in the area. If the ticks come too fast, you can turn off the sound and read off from the screen how intense the radiation is.

You use the Geiger counter to estimate the **activity** of a source. This is the number of atomic nuclei that decay every second. The unit of activity is the **becquerel** (Bq). The diver's watch in figure 45, for instance, has an activity of 2 MBq. That means that two million atomic nuclei decay in the hands of the watch every second. Relatively speaking, this is very little. The sources used at hospitals and in industry have a much higher activity.

▲ figure 45
The hands of this diver's watch contain tritium, a radioactive substance.

The half-life

There are an enormous number of unstable atomic nuclei in a radioactive source. It is impossible to predict when any one individual atomic nucleus will decay. But you can predict how long it will be before half of all the atomic nuclei will have gone. Every radioactive isotope has its own characteristic period of time for this, the **half-life** $t_{1/2}$. After that time:

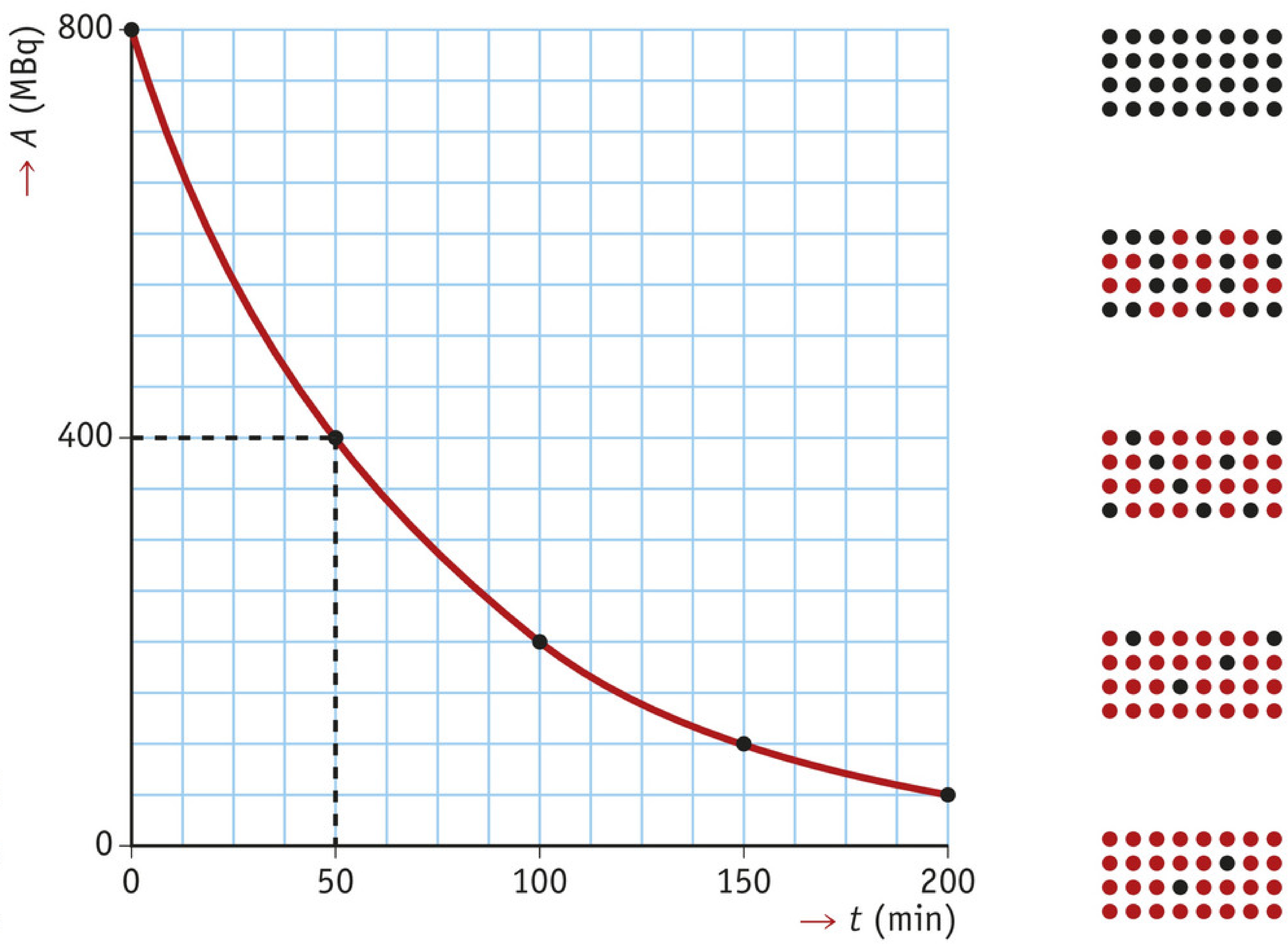
- half the unstable atomic nuclei have decayed;
- the activity of the source has decreased by half.

Radioactive isotopes have very different half-lives. For example, the half-life of uranium-238 is approximately 4.5 billion years, but the half-life of barium-144 is only 12 seconds. If the half-life is short, the substance will decay very quickly and the activity will therefore be relatively high. You can find the half-lives of some widely-used isotopes in table 6.

▼ **table 6** the half-lives of some radioactive substances

substance	is found in	application	half-life
uranium-235	rock	fuel rods in nuclear reactors	704 million years
plutonium-239	waste from nuclear reactors	atomic bombs	24,400 years
radium-226	rock	irradiation of cancer tumours	1620 years
carbon-14	the atmosphere	dating method	5730 years
caesium-137	waste from nuclear reactors	irradiation of tumours	30 years
iodine-131	waste from nuclear reactors	treatment of thyroid diseases	8 days
technetium-99m	artificially made tracers (markers)	medical investigations	6 hours

You can read off the half-life of a radioactive substance from the **decay curve**. This is a graph that plots the activity of an amount of substance against time. Figure 46 is an example. In this case, the activity decreases from 800 MBq to 400 MBq in 50 minutes. That means that the substance has a half-life of 50 minutes.



▶ **figure 46**
Over time, radioactive sources become less and less active.

Medical isotopes

Radioactive substances with half-lives ranging from hours to weeks are used at hospitals. These short-lived medical isotopes cannot be found (anymore) in nature; their lifespan is too short for this. They are made at nuclear reactors that are specially built for this purpose.

The Netherlands has one reactor that makes such medical isotopes. It is in Petten in Noord-Holland (figure 47). It is managed by the NRG, a Dutch company that produces isotopes for hospitals throughout Europe. In 2013, approximately a third of the world's production came from here.

◀ **figure 47**
the reactor building in Petten where medical isotopes are made

▲ **figure 48**
A laboratory technician preparing an injection containing highly radioactive I-131.

Worked example 2
I-131 is a radioactive isotope of iodine. Doctors use I-131 to treat thyroid dysfunctions (figure 48). Its half-life is 8 days.
At a given moment, a hospital receives a quantity of I-131 with an activity of 64 MBq.
Calculate what the activity of I-131 is after 40 days.

data	the half-life $t_{1/2}$ = 8 days activity at the start = 64 MBq
required	the activity after 40 days
working	After 8 days, the activity is still 32 MBq. After 16 days, the activity is still 16 MBq. After 24 days, the activity is still 8 MBq. After 32 days, the activity is still 4 MBq. After 40 days, the activity is still 2 MBq.

Plus Tracers

Doctors use radioactive substances to discover if organs like the kidneys or the lungs are still working properly. Such an examination is done as shown below (figure 49):

1 A laboratory makes a **tracer** (radioactive marker substance). This is a substance that is mostly absorbed by one specific organ, such as the liver or the thyroid. The tracer is made artificially radioactive by 'building in' unstable atoms. Isotopes with short half-lives that emit gamma radiation are used for this.

▶ **figure 49**

a A tracer is made in the laboratory.

b The tracer is injected into the body of the patient.

c The gamma camera registers the release of radiation.

2 The tracer is put in the patient's body. This is generally done by an injection. After that, the tracer spreads through the body and reaches the organ that is to be examined. That organ absorbs a relatively large amount of the tracer.
3 A proportion of the gamma radiation emitted by the tracer will leave the body. The radiation emitted from the body is registered by a gamma camera. A computer in the camera uses the measurements to make an image of the organ.

Exercises

46 Answer the questions below.
- **a** What measuring instrument can you use to detect sources of radioactivity?
- **b** What is meant by the 'activity of a radioactive source'? Explain.
- **c** What unit is used to measure the activity of a radioactive source?
- **d** What is the term for the ionising radiation that is always present in our environment?

47 A quantity of barium-144 ($t_{½}$ = 12 s) has an activity of 100 kBq at t = 0 s.
For this source, draw a decay curve that runs from t = 0 to t = 60 s.

48 The manual of a Geiger counter says:

> Hold an aluminium plate that is approximately 3 mm thick between the instrument and the source. If the number of clicks decreases or stops, this is very probably ... [1]. A lot of isotopes also emit ... [2]. This is why the number of clicks may decrease but not stop entirely.

Which type of radiation was left out:
- **a** at [1]?
- **b** at [2]?

***49** If you hold a Geiger counter right above a radioactive source, it registers the radiation most strongly. If you move the Geiger counter away from the source after that, the measured radiation intensity will decrease quickly.
- **a** Give two possible explanations for this.
- **b** Describe an experiment to test one of those explanations (think it up for yourself).

50 After 1945, various countries carried out experiments in which they exploded atomic weapons in the atmosphere. The last atmospheric nuclear test was held in 1980. One of the isotopes that ended up in the atmosphere in these experiments was radioactive strontium-90 ($t_{½}$ = 29 y).
- **a** Estimate the percentage of strontium-90 that will still be in the environment in 2030.
- **b** Draw a decay curve to answer this question.
- **c** Was your estimate right?

51 Hospitals often give patients a booklet with information before an examination. Figure 50 shows a fragment from such a booklet.

a What is the half-life of the radioactive substance that is used in the examination?

b Why is the mother's milk expressed and destroyed during the first 24 hours after the examination?

c Radioactive material with an activity of 1200 MBq is given during this examination.
Explain what is meant by an 'activity of 1200 MBq'.

d The activity of the substance given keeps decreasing.
What is the activity 24 hours after the substance was given?

After the examination, you will have to stop breastfeeding temporarily. The mother's milk must be expressed during that period and will then be destroyed. Breastfeeding can start again when the radioactivity has dropped sufficiently. Fortunately, the substance used has a short half-life, half of its radioactivity will already have gone after 6 hours. You can breast-feed your child again 24 hours after the start of the examination

▲ **figure 50**
a fragment from a hospital brochure

52 Table 7 lists a few of the medical isotopes that are supplied by the reactor in Petten.

a More than 50% of some of these isotopes remain after a month.
Which are they?

b A little over half of one of these isotopes remains after a week.
Which is it?

c More than half of one of these isotopes has decayed after only two days.
Which is it?

▼ **table 7** a few medical isotopes

isotope	half-life
iridium-192	73.8 days
iodine-125	60.1 days
iodine-131	8.04 days
rhenium-186	3.78 days
samarium-153	1.95 days
strontium-89	50.5 days
xenon-133	5.25 days

Source: www.nrg.eu/nl/irradiation-development/medische-isotopen/

***53** Two radioactive sources are used in an experiment: one contains iodine-131, the other iodine-125. Both sources have the same activity at a given moment.
Use table 7 to calculate:

a which source contains the largest amount of iodine at that moment.

b which source's activity will decrease faster.

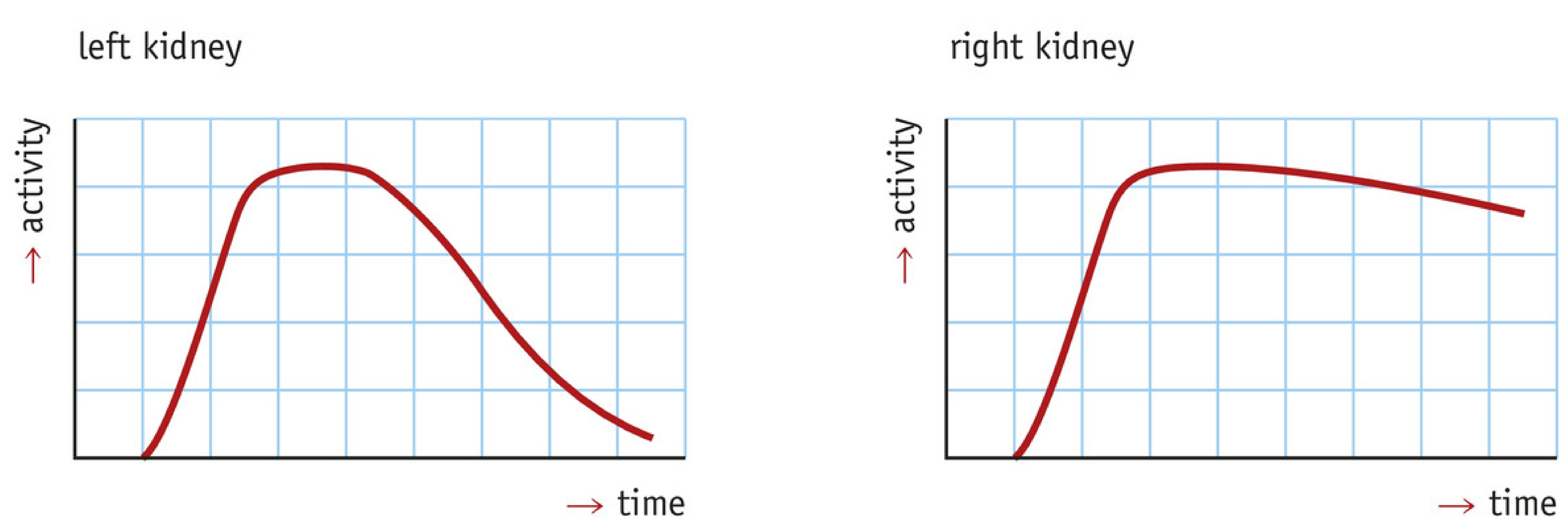
***54** The substance CO_2 in the atmosphere has a constant percentage of the radioactive isotope ^{14}C. During their lives, trees absorb CO_2 from the air and they therefore also contain ^{14}C. This absorption stops when the tree is felled. The nuclei of ^{14}C atoms that decay from that moment on will not be replaced. The half-life of ^{14}C is 5730 years.
How old is a piece of wood in which the activity is only one eighth of the original activity?

55 Search the Internet for information about a medical isotope of your own choice.
- **a** For which examinations and/or treatments is the isotope used?
- **b** How is such an examination or treatment done? Choose one example.
- **c** What is the purpose of the examination or treatment?
- **d** Do the patients have to do anything to prevent contamination? If so, what must they do? If not, why do they not need to worry?

Plus Tracers

56 Medical tracers are created to be artificially radioactive.
Explain why the isotopes used for this:
- **a** have short half-lives.
- **b** emit gamma radiation during their decay.

***57** How the kidneys work can be examined with a tracer that is made with radioactive technetium-99m. The tracer is placed in the bloodstream by an injection. If the patient's kidneys are working well, the tracer will leave the kidneys quickly, be taken to the bladder, and end up in the urine.
- **a** Detectors are used to measure the activity in the kidneys. Figure 51 shows you how the activity in the kidneys changes over time.
  Which kidney is working well and which is not? Explain how you can see that.
- **b** The half-life of technetium-99m is 6 hours.
  Explain why 6 hours is a good value for this examination. Give two reasons for this.



▶ **figure 51**
the activity of a patient's kidneys as a function of time

Test Yourself

You can also do questions 1 to 16 on the computer.

1 Copy and complete:
- **a** Radio waves have the longest wavelengths of all types of … radiation.
- **b** The wavelengths of visible light lies between the wavelengths of infrared and … .
- **c** In the spectrum of light, red has the … wavelength and violet the … .
- **d** The wavelength of … (< 10 pm) is shorter than the wavelength of X-rays.

2 At what speed do electromagnetic waves propagate?
- A approximately 300,000 m/h
- B approximately 300,000 km/h
- C approximately 300,000 km/s
- D approximately 300,000 m/s

3 Select the correct options.
X-rays:
- **a** *pass through / are absorbed by / are reflected by* muscles and fatty tissue.
- **b** *pass through / are absorbed by / are reflected by* the bones in your body.

4 Blood vessels cannot normally be seen on X-rays. If the blood vessels have to be made visible, the patient is given an injection of a contrast fluid before the examination.
What property must this contrast fluid have?
- A It must absorb X-rays.
- B It must allow X-rays to pass through.
- C It must emit X-rays.
- D It must reflect X-rays.

5 Copy and complete. Choose between: *not – slightly – strongly*.
- **a** Gamma radiation is … ionising.
- **b** Infrared radiation is … ionising.
- **c** Visible light is … ionising.
- **d** X-rays are … ionising.
- **e** Ultraviolet radiation is … ionising.

6 Table 8 shows the structure of particles P and Q. State whether the following statements are true or false.
- **a** Justin says, “P and Q both have the same atomic number.”
- **b** Thomas says, “P and Q both have the same mass number.”
- **c** Vincent says, “P and Q are isotopes of the same element.”

▼ **table 8** the composition of two atoms

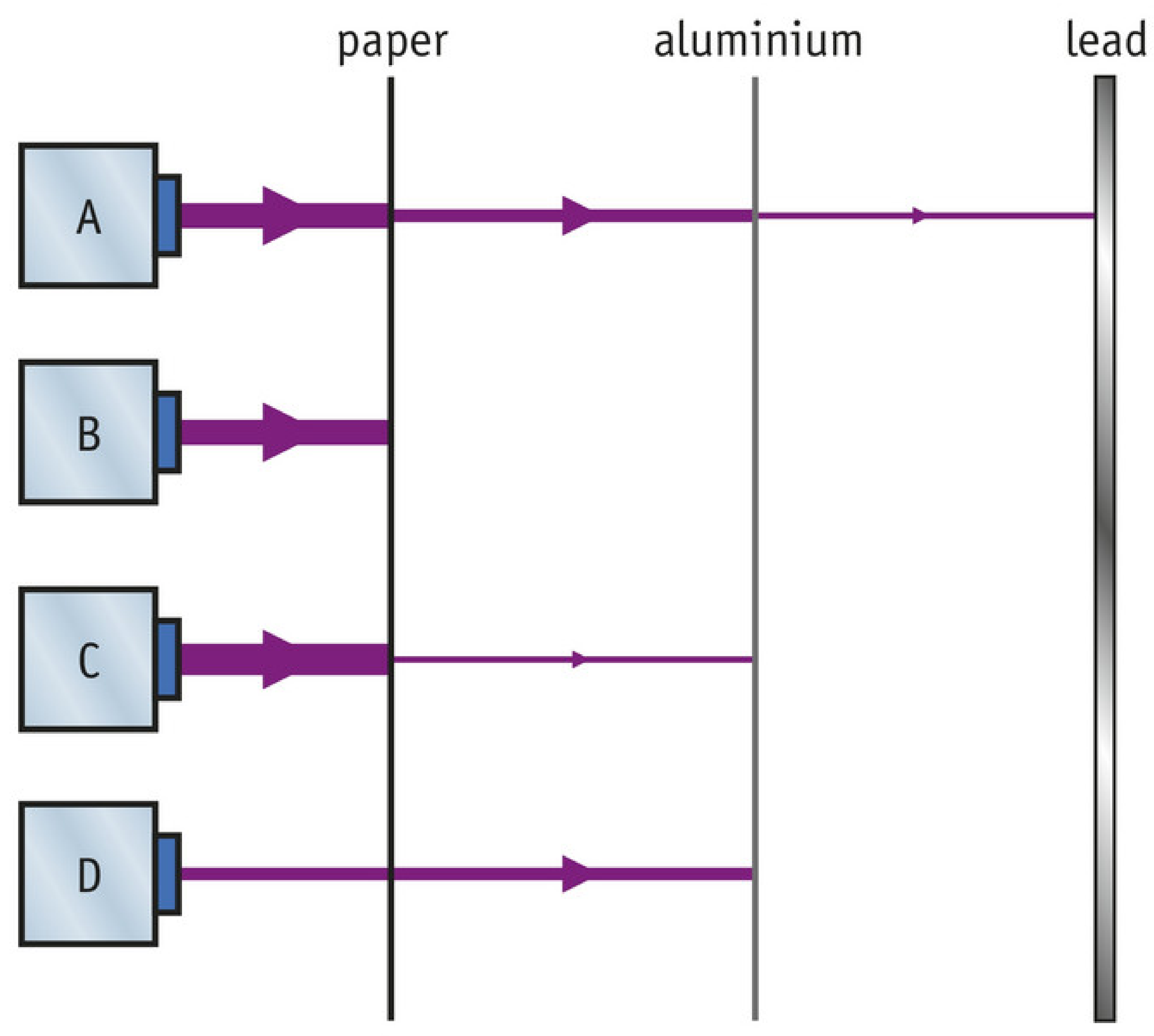
atom	protons	neutrons	electrons
P	18	22	18
Q	20	20	18

7 Cl-35 and Cl-37 are two stable natural isotopes of chlorine.
What is the difference between a Cl-37 atom and a Cl-35 atom?
- A A Cl-37 atom has 1 proton and 1 neutron more in its nucleus.
- B A Cl-37 atom has 2 protons more (and equally many neutrons).
- C A Cl-37 atom has 2 neutrons more (and equally many protons).
- D You cannot tell unless you know the atomic number of chlorine.

8 Two examples of radioactive decay are given below.
Copy the examples and fill in the missing numbers.
- **a** $^{238}_{94}\text{Pu} \rightarrow {}^{\dots}_{\dots}\text{U} + {}^{4}_{2}\text{He}$
- **b** $^{90}_{38}\text{Sr} \rightarrow {}^{\dots}_{\dots}\text{Y} + {}^{0}_{-1}\text{e}$

9 Copy and complete:
- **a** Ionising radiation can cause a lot of damage in the body, by breaking down … in the cells.
- **b** The degree of damage depends on the … of radiation that someone absorbs, and on the … of radiation.
- **c** The equivalent dose, for which the unit of measurement is the …, shows how much damage has been caused.
- **d** When the equivalent dose is calculated, … is more heavily weighted than … or gamma radiation.

10 Four different radioactive sources are put in front of plates of different materials (figure 52). The thickness of the arrows is a measure of the amount of radiation.
Which source emits:
- **a** only α-radiation?
- **b** only β-radiation?
- **c** both α-radiation and β-radiation?
- **d** both α-radiation, β-radiation, and γ-radiation?



▲ **figure 52**
What type of radiation is emitted by each source?

11 Which metal is widely used to shield gamma radiation?
- A aluminium
- B lead
- C uranium
- D silver

12 Study the following situations:
1. The dentist has made an X-ray of Albert's molar and Albert has been exposed to a radiation dose of 0.005 mSv.
2. Betty has eaten a handful of Brazil nuts. These nuts contain (for a food) a remarkable amount of radium.
3. Karen makes her sandwiches on a granite top in the kitchen. Granite contains a small proportion of radioactive uranium.
4. David is a heating technician and he regularly works in crawler spaces that have high levels of the inert radioactive gas radon.

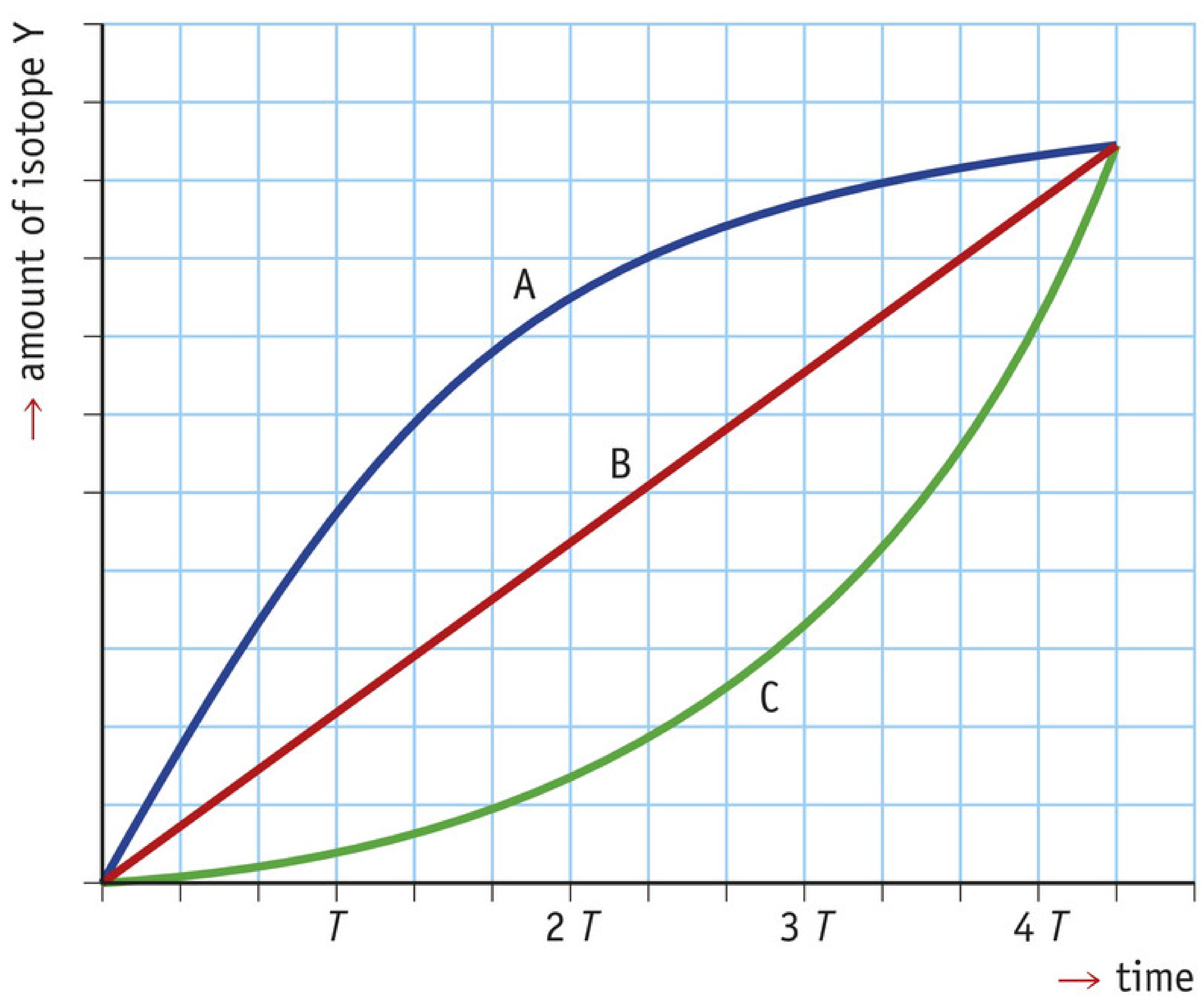
- **a** In which situations will he only be irradiated?
- **b** And in which situations will he be contaminated?

13 A radioactive isotope X with a half-life of T decays into a stable isotope Y. At $t = 0$, there is no Y in the source yet.
Which graph (A, B or C) in figure 53 shows the correct increase of isotope Y?

14 80 mg of xenon-133 is put in a safe in a hospital. The half-life of this radioactive isotope is 5.25 days.
Calculate how many milligrams of this substance will be left after three weeks.

15 A radioactive source contains the isotope vanadium-48. The half-life of this isotope is 16 days.
After how many days will 90% of the vanadium-48 atoms have decayed?

A	approx. 53 days	D	approx. 89 days
B	approx. 65 days	E	approx. 101 days
C	approx. 77 days	F	approx. 113 days



▲ **figure 53**
Which graph shows the increase of isotope Y correctly?

16 State whether the following statements are true or false.

a In a vacuum, all types of electromagnetic radiation propagate at the speed of light.
b X-rays are strongly absorbed by the muscles, but your bones allow almost all radiation to pass through.
c At extremely low temperatures, radioactive substances decay more slowly than at room temperature.
d If people are radioactively contaminated, they will become radioactive too.
e The background radiation is never zero, because there is always some radioactivity in your environment.

17 Welders wear welding hoods (figure 54). The glass in these hoods stops infrared radiation, light and ultraviolet.

a Suppose that the welder did not wear a hood. Which type of radiation would then:
– be too blinding for the welder to be able to do the work?
– permanently damage the welder's eyes?
– make the welder's face very hot?
b Which type of radiation must not be completely blocked? Explain why.

▲ **figure 54**
welding with a welding hood

18 A company irradiates potatoes to destroy parasites and microorganisms, and to inhibit germination. For this purpose the potatoes are placed on a conveyor belt, after which they go under a radiation source. The source contains cobalt-60, a radioactive isotope that produces beta and gamma radiation. The half-life of cobalt-60 is 5.3 years. In 2007, they started using a new cobalt-60 source that could irradiate 10,000 kg of potatoes a day at that moment.

a As time progresses, the speed of the conveyor belt has to become slower and slower. Explain why this is needed.
b During the course of 2017, the amount of potatoes going under the source will have to be reduced to:
A 7500 kg a day.
B 5000 kg a day.
C 2500 kg a day.
D 1250 kg a day.
c The beta radiation hardly does anything to destroy the microorganisms in the potatoes. Why is that?

19 You need worksheet 7-1 for this exercise. A laboratory measures the amount of radiation emitted by a radiation source. You can find the results of this measurement in table 9. The amount of radiation has been measured in becquerels (Bq).

a Draw the decay curve for these measurements on the worksheet.
b What is the half-life of the radioactive substance?
c Has the activity of this source decreased to 0 Bq after 10 minutes? How do you know that?

▼ **table 9** a radioactive source

time (min)	activity (Bq)
0	720
1.0	450
2.0	285
3.0	180
4.0	110
5.0	70
6.0	45

20 A factory is checking the thickness of steel plates. To do this, the steel plates are placed under a radiation source (figure 55a). A radiation meter measures the amount of radiation that the plate lets pass. Figure 55b shows you how the amount of radiation that is let through depends on the thickness of the plate.

a The available radiation sources are the isotopes in table 10.
Explain which isotope has to be chosen as the radiation source. Give two reasons for this.

b A plate is the correct thickness if it lets 40% of the radiation pass.
Calculate how thick the plate must be.

c The plate lets through 45% of the radiation at one point.
Is the plate too thick or too thin there? Explain your answer.

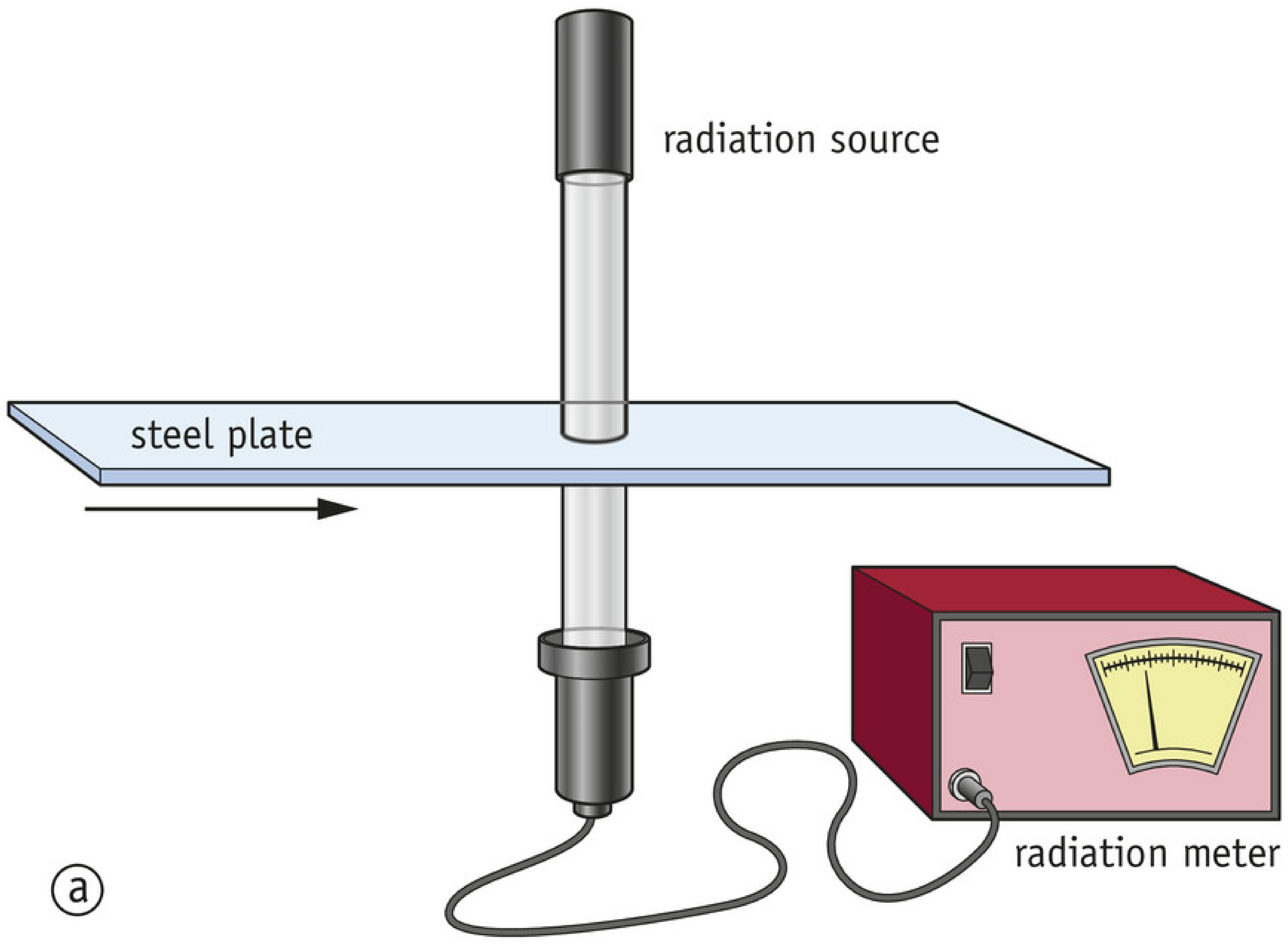
▼ **table 10** various isotopes and their properties

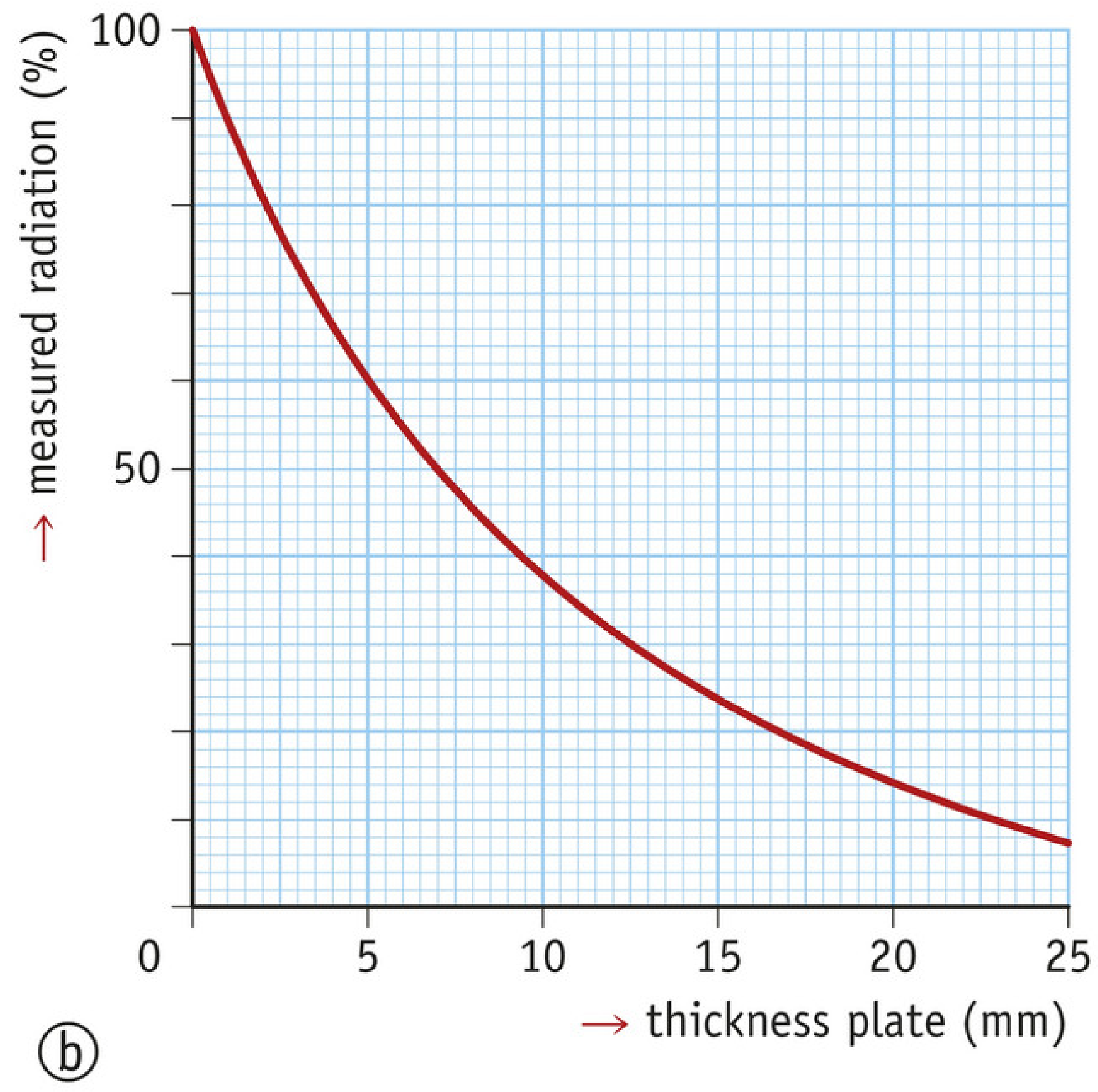
isotope	type of radiation	half-life
strontium-90	β	28 years
cobalt-60	β, γ	5 years
cerium-141	β, γ	32 days

21 Figure 56 shows the amount of not yet decayed nuclei *N* of a radioactive substance in relation to time *t*.

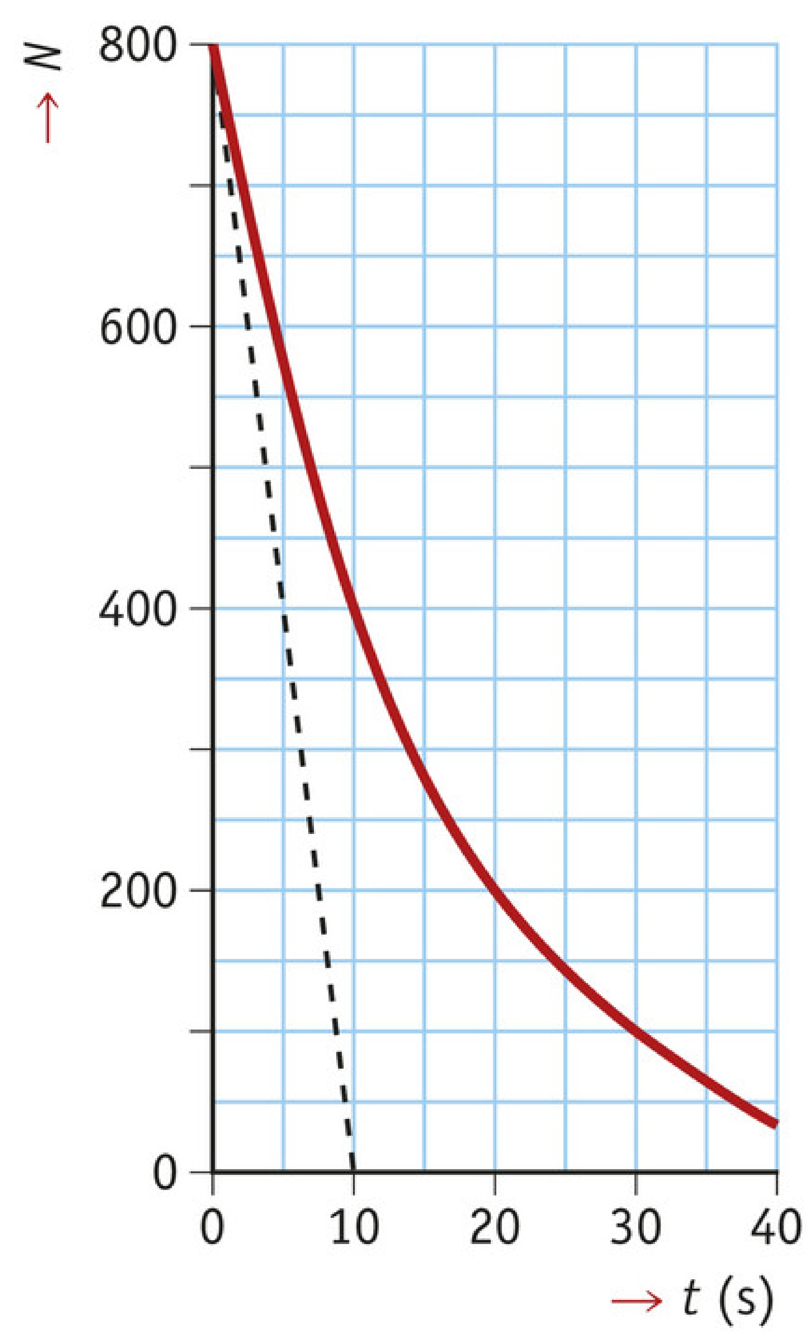
a What was the activity at $t = 0$?
A 10 Bq
B 80 Bq
C 800 Bq
D 8000 Bq

b What is the half-time of the substance?

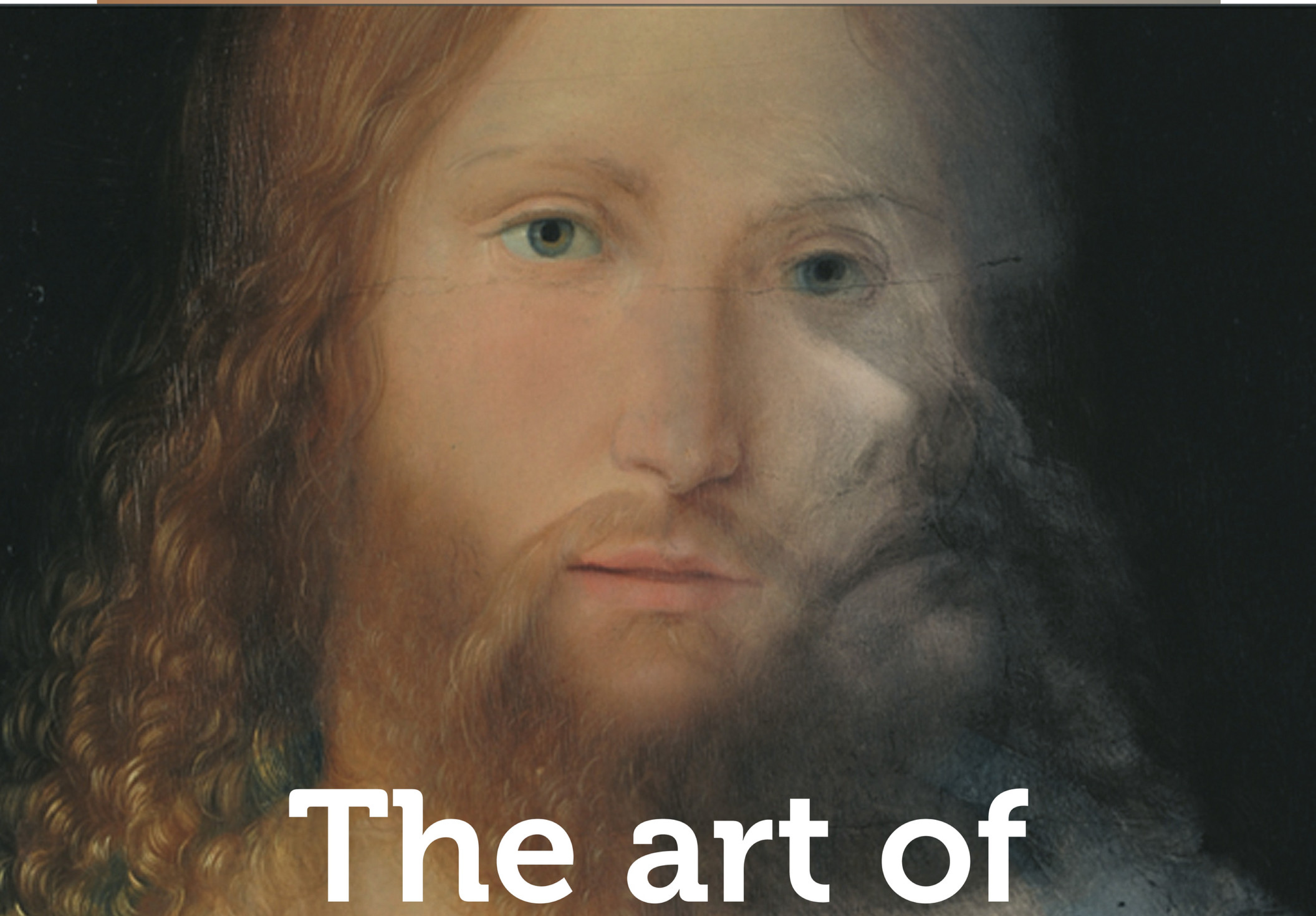




▲ **figure 55**
The thickness of the plate can be determined this way



▲ **figure 56**



The art of unmasking

It is the nightmare of every art collector, paying a six-figure sum for a painting from the Dutch Golden Age and having to hear later on, "I'm so sorry Sir, Madam, we have examined it and unfortunately there is no doubt: your painting cannot possibly be a painting from the seventeenth century. The canvas is antique, but the paint is recent, not even forty years old. It seems you have been cheated..."

Art lovers are not the only ones who are cheated. It also happens to real professionals. A few years ago, there was commotion in Belgium about a *Madonna and Child* by – or so everyone thought – the old master Rogier van der Weyden (1499–1464). The painting had been at the Museum of Fine Arts in Tournai for fifty years and experts said it was a masterpiece.

Everyone was therefore very much surprised when the truth came to light. An investigation showed that the *Madonna and Child* was the work of a forger from the twentieth century. "Nothing on the canvas is from the fifteenth century," says Roger van Schoute, one of the experts, while shaking his head, and yet the painting looks totally authentic, even down to the *craquelure* (the small cracks in the paint).

Art experts will not readily admit it, but a really good forgery cannot be identified with the naked eye. That is why collectors and museum directors rely more and more often on scientific investigations. Paintings can be examined in various ways: not only with visible light, but also with infrared, ultraviolet and X-rays. Each form of radiation shows details that otherwise cannot be seen.

Hidden layers

An oil painting has a complex structure with various layers of different thicknesses. The bottom layer is the support, stretched canvas or a wooden panel. The painter would cover it with a gouache filler layer first. After that, he made a charcoal drawing of the composition that he had thought up.

Only then would he start painting with oil paints. This was done in layers too: first an underpainting with relatively little colour, and thin semi-transparent layers of paint after that. That slowly resulted in a painting with deep and lifelike colours. Finally, the painting was given a transparent varnish as protection against dust and dirt.

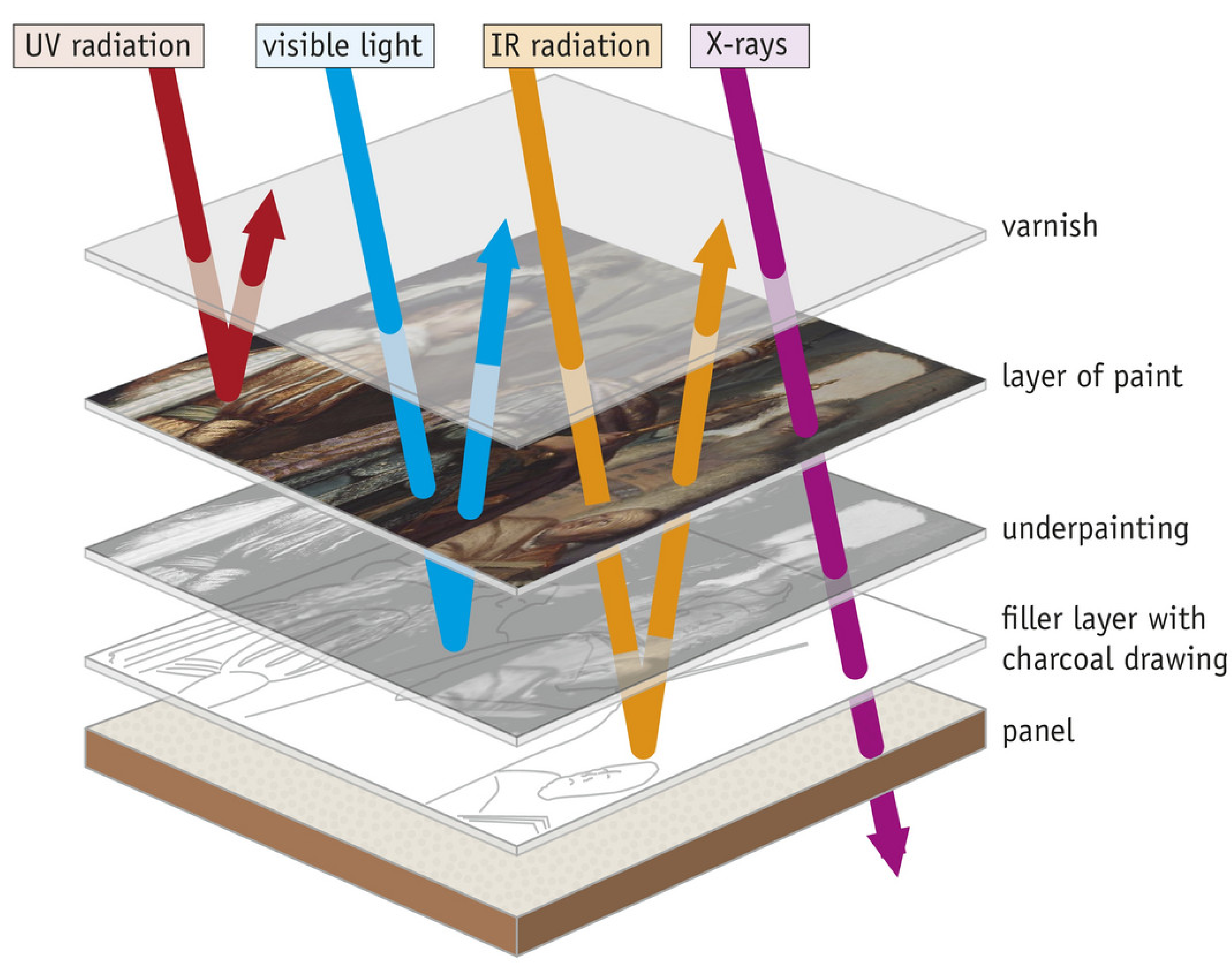
Art experts will not readily admit it, but a really good forgery cannot be identified with the naked eye.

Screening a painting

There are techniques for studying each layer. For instance, the varnish layer can be checked with UV. This will make the varnish glow, just like a banknote that glows under a UV lamp. You can see how old the varnish is by the way that the varnish layer fluoresces (glows). The natural varnishes from earlier times emit a green-yellow light. Modern synthetic varnishes glow white or purple.

X-rays are used to study the deeper layers of paint. Each layer of paint consists of granules of pigment (the coloured dye) in a binding agent such as linseed oil. Most pigments let X-rays pass without any problem. But pigments containing heavy metals such as lead or mercury do not. They absorb X-rays and are therefore clearly visible on an X-ray photo.

Pigments with heavy metals used to play an important role in the art of painting. The old masters used compounds such as white



lead, lead-tin yellow and vermilion (a red compound of mercury and sulphur). These pigments are highly toxic. They are almost never used these days, but once they could be found in every artist's studio.

White lead was an important component of the underpainting: the first general version of an oil painting that was used as the basis for the next layers. Because of the absorbent white lead, such an underpainting can be seen clearly on an X-ray photo. In general, the underpainting should be the same as the painting you see. If the underpainting looks very different, this is an indication for fraud.

Reflections in infrared

Charcoal is made of carbon, which is transparent to X-rays. That is why an X-ray photo does not show you anything of the original charcoal drawing made by the painter. To make sure this drawing can be seen, investigators use infrared (IR). This works better, because charcoal is deep black and absorbs IR radiation strongly.

The IR radiation passes through the layers of paint of the painting, after which it is reflected by the gouache layer and then travels outside again. This will be different at points where charcoal has been used. The IR radiation is absorbed there and little or no reflected radiation comes from these regions.

A special infrared camera catches the reflected radiation and converts it into a black and white image. It shows the charcoal drawing surprisingly clearly. Investigators look carefully at such a drawing to see if it is by the master painter himself. If so, it is highly probable that the painting is an original work. If not, the painting has probably been made by someone else.

Carbon-14 dating

Paintings always contain organic materials, such as the canvas or the wood panel that is painted on. These materials come from plants and can therefore be dated by the carbon-14 method. The age of the materials can be calculated pretty accurately by looking at the amount of radioactive carbon-14 left in these materials.

The carbon-14 method

Cosmic radiation from the universe generates new carbon-14 in the atmosphere all the time. As a result, the ratio in the atmosphere of stable carbon-12 to radioactive carbon-14 remains more or less constant.

Throughout its entire life, a plant absorbs carbon from the atmosphere. That is why both isotopes are found in the plant, in the same ratio as in the atmosphere. That changes when the plant is harvested, a dead plant does not absorb carbon-14 anymore. The amount of carbon-14 in it will become less and less because of natural decay. Investigators can calculate the age of the material by measuring the ratio between the remaining carbon-14 and carbon-12.

If the carbon-14 method gives an age that is much too young, then you know that the painting must be a forgery. This is not necessarily the case for the reverse. A forger can buy an old but worthless painting and simply paint his forgery over it. Additional studies are always needed in addition to carbon-14 dating to be sure if the painting is real.

That additional study is the key. If a painting is a forgery, there are always things that are not right. But you never know beforehand what you have to look for. You are even not sure whether it is a forgery. You have to learn to keep on searching patiently until you find the one mistake that unmasks the fraud.

Exercises

1 The varnish on a painting will start to fluoresce when UV radiation lands on it. At the same time the varnish also emits radiation.
- **a** Between which limits is the wavelength of the emitted radiation? How can you tell this?
- **b** Explain why it is not wise to expose a painting to strong UV radiation for a long time.

2 X-ray photos are often used when old paintings are being investigated. The painting is put down flat for this purpose with the X-ray source a little above it and the radiation detector below it.
- **a** Does it make any difference whether the investigator lays the painting face up or face down? Explain.
- **b** Why is the underpainting clearly visible on an X-ray photo, whereas the layers of paint on top of it are almost invisible?
- **c** Can you see what pigment is used in a certain layer on an X-ray photo? Explain why or why not.

3 Search the Internet for a *carbon dating calculator*.
- **a** The canvas of a painting still contains 95% of the original amount of carbon-14. How old is the canvas therefore?
- **b** A well-known painting by the Italian painter Giotto was painted on a wooden panel around 1310. How much of the original amount of carbon-14 (at most) would be left in the wood?
- **c** Why does question b say ‘at most’? Explain.

Skills

Gathering and processing data

Physics is often about both knowledge (what you know) and skills (what you can do). The skills include aspects such as building experimental setups, collecting the measurement data, performing calculations and drawing graphs. This part of the book gives you a summary.

1	Carrying out research	304
2	Working with variables and units	305
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1 Carrying out research

Research starts with a question that you are studying. You make a plan to find the answer, and then you carry out that plan yourself. You do this step by step.

- **Step 1: Think up a study question.**
  Sometimes this will already by stated in the exercise. In that case, all you have to think about is how you can answer the question. Sometimes you are expected to think up a study question of your own. Don't be content with it too quickly: you must also have some idea how you could answer your question. Formulate your study question as precisely as possible before you go any further.

- **Step 2: Make a work plan.**
  In your working plan, you should write down:
  - what variables you are going to measure;
  - what materials and equipment you will need;
  - what experimental setup you are going to construct (make a drawing);
  - what measurements you are going to make;
  - which formulae you are going to use (if applicable).

- **Step 3: Do the experiment and write it up.**
  You construct the experimental setup and use it for carrying out the measurements as planned. After each set of measurements you make a note of the measured values, for example in a table. After you have finished, you work out the measurements in more detail, for instance by drawing a graph or doing calculations. If necessary, use the other skills for this too.

- **Step 4: Draw conclusions.**
  If everything went smoothly you can now draw your conclusions. Taken together, the conclusions provide the answer to the study question. A conclusion is not a summary of the measured results, it is something that you can derive (conclude) from the measurements. You should also think about what you could have done better in your research.

- **Step 5: Write a report.**
  Finally, you make a report of your research. See Skills 10.

2 Working with variables and units

A variable is something that you can measure. Examples of variables are mass, force, resistance and time. To be able to measure a variable, you need units in which to express it. You measure mass in kilograms, force in newtons, resistance in ohms and time in seconds.

The size of a unit is often not convenient for the variable you want to measure. In that case, you can put a multiplier prefix before the unit. Instead of saying that the thickness is 0.0003 metres, you would write "The thickness is 0.3 mm."

You can always replace these prefixes with a power of ten (and vice versa). Instead of saying "Insulating the pipes saves you 4.8 GJ of heat" you could also write: "Insulating the pipes saves you $4.8 \cdot 10^9$ J of heat." See table 1.

▼ **table 1** prefixes and their meanings

prefix	abbreviation	meaning	example
giga	G	10^9	1 GJ = 10^9 J
mega	M	10^6	1 MW = 10^6 W
kilo	k	10^3	1 kN = 1000 N
hecto	h	10^2	1 hPa = 100 Pa
deca	da	10^1	1 dam = 10 m
deci	d	10^{-1}	1 dL = 0.1 L
centi	c	10^{-2}	1 cm = 0.01 m
milli	m	10^{-3}	1 mΩ = 0.001 Ω
micro	µ	10^{-6}	1 µg = 10^{-6} g
nano	n	10^{-9}	1 ns = 10^{-9} s

Sometimes there are several units that are in use for the same variable. Take temperature for instance (°C and K) or energy (J and kWh). In that case, you sometimes have to convert a value from one set of units to another.

Worked example 1
A website says that the average temperature on Mars is 210 K.
How many degrees Celsius is that?

T (in K) = t (in °C) + 273

$210 = t + 273 \rightarrow t = 210 - 273 = -63$ °C

Worked example 2
According to a consumer organisation, an average family in the Netherlands uses ± 3500 kWh of electrical energy per year.
What is that in joules?

$1\ \text{kWh} = 3.6 \cdot 10^6\ \text{J}$

$3500\ \text{kWh} = 3500 \times 3.6 \cdot 10^6\ \text{J} = 1.26 \cdot 10^{10}\ \text{J}$ (or 12.6 GJ)

3 Working with powers of 10

In physics, you often have to deal with numbers that are extremely large or extremely small. There is a handy way of writing numbers like those. For large numbers, you use positive powers of 10. For small numbers, you use negative powers of 10.

positive powers	**negative powers**
$10^1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1/100 = 0.01$
$10^3 = 10 \times 10 \times 10 = 1000$	$10^{-3} = 1/1000 = 0.001$
etc.	etc.

If you want, you can replace the power of 10 with a prefix. Instead of writing “The capacity of the power plant is $4.75 \cdot 10^8$ W”, you can also write “The capacity of the power plant is 475 MW.” Work it out:
$4.75 \cdot 10^8\ \text{W} = 475 \cdot 10^6\ \text{W} = 475\ \text{MW}$ ($\text{M} = 10^6$). See table 2 for examples.

Worked example 3
The nuclear power plant in Gravelines (in France) has an electrical output of 5460 MW. In practice, only 75% of this capacity is actually delivered. On average, 25% of the capacity is not available, mostly because of maintenance.
Calculate how many kWh of electricity the nuclear power station produces in one year.

75% of 5460 MW = 4095 MW
$P = 4095\ \text{MW} = 4095 \cdot 10^6\ \text{W} = 4095 \cdot 10^3\ \text{kW}$
$t = 365 \times 24 = 8760$ hours

$$\begin{aligned} E &= P \cdot t \\ &= 4095 \cdot 10^3 \times 8760 \\ &= 3.5872 \cdot 10^{10}\ \text{kWh} \approx 36 \cdot 10^9\ \text{kWh} \end{aligned}$$

The power station produces 36 billion kWh of electrical energy every year.

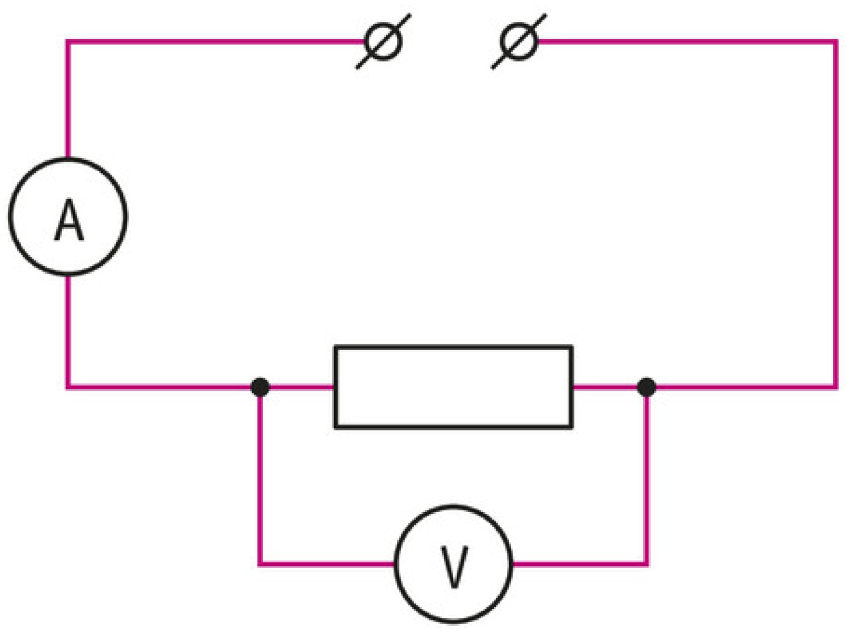
▼ **table 2** examples of powers of 10 from nature

	length (m)	mass (kg)	time (s)
10^{-10}	diameter of an atom		
10^{-9}			
10^{-8}	diameter of the smallest virus		
10^{-7}		mass of a sand grain	
10^{-6}	diameter of a bacterium	mass of a raindrop	
10^{-5}	diameter of a red blood cell		
10^{-4}	thickness of paper	mass of a fly	duration of a lightning flash
10^{-3}			
10^{-2}	thickness of a finger	mass of a mouse	
10^{-1}			reaction time of a human
10^{0}	height of a human	mass of a bag of sugar	time between two heartbeats
10^{1}			world record for the 100 m sprint
10^{2}	length of a supertanker	mass of a human	
10^{3}		mass of a car	a quarter of an hour
10^{4}	maximum depth of the oceans		
10^{5}		mass of a jumbo jet	one day
10^{6}	diameter of the Moon		
10^{7}	diameter of the Earth		one year
10^{8}		mass of a supertanker	
10^{9}			lifespan of a human
10^{10}			
10^{11}	distance from the Earth to the Sun		age of the pyramids
10^{12}			

4 Working with measuring instruments

You use all kinds of measuring instruments in physics. To measure things properly, you have to take it step by step.

- **Step 1: Determine what measuring instruments you need.**
  For an experiment, you will want to answer a question such as:
  Is the electrical rating stated on this appliance correct?
  You know that you can determine the electrical power (the rating) using the formula $P = U \cdot I$. That means that you have to measure the voltage (U) and the current (I). So you need two measuring instruments: a voltmeter and an ammeter.



▲ **figure 1**
How to connect up a voltmeter and an ammeter.

- **Step 2: Connect up the measuring instrument.**
Voltmeters and ammeters have to be connected up correctly: an ammeter in series with the device, a voltmeter in parallel (figure 1).
For direct currents and voltages, the direction the current is flowing in is also important. You have to connect the plus terminal of the meter to the positive terminal of the voltage source and the minus to the negative terminal. The plus terminal is usually a red jack socket and the minus is usually black (figure 2).

▶ **figure 2**
What is the current?

- **Step 3: Select the correct measurement range.**
Ammeters and voltmeters often have more than one measurement range. You can find out which measurement range you should be using as follows:
  - Make a test measurement using the greatest measurement range.
  - This lets you see roughly how big the current or voltage is.
  - Then choose the smallest measurement range in which the meter can still be read.
    The smaller the measurement range you use, the more accurate the measured result will be.

- **Step 4: Read the measuring instrument.**
Many measurement instruments have a graduated scale. When you are taking a reading from a measuring instrument like this, you first have to determine how much each mark on the scale represents. Then you read the value off as accurately as possible.
In the ammeter in figure 2, for example, it goes like this:
  - I have used the measurement range from 0 to 0.5 A.
  - Between 0.3 and 0.4 A, there are ten gaps (nine marks).
  - Each mark is therefore worth 0.1 ÷ 10 = 0.01 A.
  - The needle is pointing to the sixth mark.
  - The current is therefore 0.36 A.

5 Working with formulae

Physics often requires you to do calculations. You should take a step-by-step approach to this.

- **Step 1: Read the exercise.**
  Read the exercise carefully and make an estimate of roughly what the answer should be. In worked example 4, it asks you how long a kettle will take to boil one cup of water. You know that you will have to wait a few tens of seconds or a minute or so. If you get an answer of a couple of seconds, that is clearly too little. Similarly, five minutes is clearly too long.

- **Step 2: Write down the data.**
  Convert all the data into letter symbols and numbers, and make a note of it. A data item such as '44 kJ of heat' should for example be written down as: $E = 44$ kJ $= 4.4 \cdot 10^4$ J.

- **Step 3: Write down the formulae.**
  Some formulae can be written in different ways. You should use the form in which the variable that you want to calculate is in front of the equals sign (=). So you write:

  $E = P \cdot t$ if you want to work out the amount of energy (E);

  $P = \dfrac{E}{T}$ if you want to calculate the power (P);

  $t = \dfrac{E}{P}$ if you want to calculate the time required (t).

- **Step 4: Fill in the data.**

- **Step 5: Do the calculation.**

- **Step 6: Make a note of the result.**
  The result is a number plus a unit. The unit must match the data: if you give the power in watts (W) and the time in seconds (s), you will get the amount of energy in joules (J). Also see Skills 6 for how to round off the result.

- **Step 7: Check the answer.**
  Compare the result against the estimate that you made at the start. You should also check that you did not make any calculation errors or mistakes when copying the numbers down.

Worked example 4
Boiling water for a cup of tea requires 44 kJ of heat.
How long does a kettle of 1800 W take to supply this amount of heat?

data $E = 44\ \text{kJ} = 4.4 \cdot 10^4\ \text{J}$
$P = 1800\ \text{W}$

required $t = ?$

working $t = \dfrac{E}{P} = \dfrac{4.4 \cdot 10^4}{1800} \approx 24\ \text{s}$

6 Rounding off results

The results of a calculation cannot be more precise than the data that you used. This means that the results of a calculation often have to be rounded off. Otherwise, it gives the impression of being a very accurate result when it really is not.

The result of a multiplication is rounded off as follows:

- The answer must have as many digits as the number in the exercise that has the fewest significant figures. Significant figures are the numbers that matter in determining how precise a number is. The height on a Dutch identity card, for example, is given to three significant figures: 1.76 m, for instance, or 1.90 m.
- Zeroes at the start of a number do not matter when you are counting the number of significant figures: 25 cm has just as many significant figures as 0.25 m. Some more examples:
  - 2.0 has two significant figures, but 0.2 only has one significant figure;
  - 0.22 and 0.022 both have two significant figures;
  - 2.02 has three significant figures.
- To round off correctly, you look to see the first digit that has to be dropped. If that is 5 or more, you have to ‘round up’. That means that the digit before it has to be increased by 1. If the digit you are dropping is 4 or less, you do not have to increase the digit before it.

If you have to give an answer in three figures:
- you round 2.345 to 2.35;
- you also round 2.354 to 2.35;
- you round 2.395 to 2.40;
- you also round 2.404 to 2.40;
- and so forth.

Worked example 5
When there is a voltage of 134 mV across a resistor, the current through it is 1.9 mA.
Calculate the resistance.

data U = 134 mV = 0.134 V
I = 1.9 mA = 0.0019 A

required R = ?

working $R = \dfrac{U}{I} = \dfrac{0.134}{0.0019} \approx 71\ \Omega$

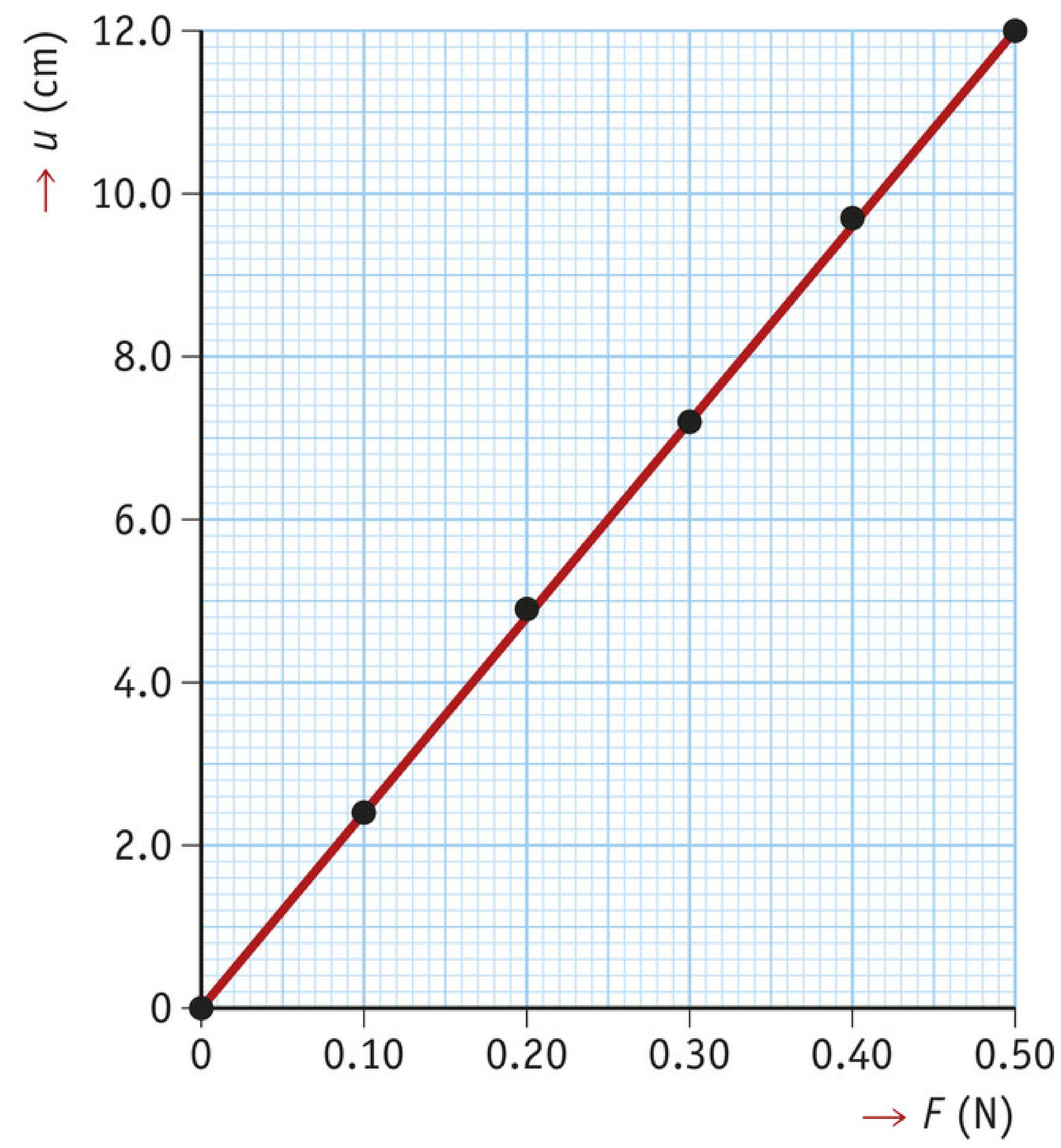
Explanation
If you do the sum on a calculator, the answer you will get is 70.526316. The data item I = 1.9 mA has the fewest significant figures, two. You should therefore also give your answer to two significant figures. So you drop all the numbers after the 70. However, because the first digit that you are dropping is a 5, you have to increase the digit in front of it and the 0 becomes a 1. The correctly rounded result is therefore 71 Ω.

7 Working with tables and graphs

Many of the study questions are about the relationship between two variables. Take the following study question, for example:
What is the relationship between the extension of a spring and the force that is exerted upon it?
This question is about the relationship between the force and the extension.

To answer the question, you carry out a series of measurements. You hang weights on the spring, measuring how far it extends each time. You then write down the measured results in a table. After completing the experiment, you show the measurement results from the table in a graph.

You make the graph as shown in figure 3.



▶ **figure 3**
a graph of extension against force

- **Step 1: Draw a set of axes.**
- **Step 2: Label each axis with a variable and the corresponding units.**
  For example: → *F* (N) and → *u* (cm).
- **Step 3: Draw an appropriate scale along each of the axes.**
  Make sure that the biggest numbers still fit on it.
- **Step 4: Plot in the measurements as points.**
- **Step 5: If all the points are (roughly) on a straight line, draw a straight line through them.**
  If they are not, draw a smooth curve. Make sure that the line fits the points as well as possible, but never 'join the dots' one by one. It does not matter if the straight line or curve does not go precisely through all the measurement points.

8 Measuring relationships

Many of the study questions are about the relationship between two variables. For example, take the following study question:
What is the relationship between the extension of a spring and the force that is exerted upon it?
In this question, the variables are the force (on the spring) and the extension (of the spring).

How can you measure this kind of relationship? A few hints:

- **Step 1: First make a table in which you can write down the measurement.**
  Note the force on the left and the extension on the right.

- **Step 2: Choose a series of 'nice' numbers for the variable in the left-hand column.**
  If you are hanging weights of 10 grams on the helical coil, the force (in N) would, for example, have the following values: 0, 0.1, 0.2, 0.3, 0.4 and so on.
  That will make it easier to draw the graph later on.

- **Step 3: Write down the measurement values in the table: the force (in N) on the left and the extension (in cm) on the right.**

- **Step 4: Turn your measurements into a graph.**
  Skills 7 tells you how to do that. Put the force along the horizontal axis and the extension on the vertical axis.

- **Step 5: Compare your graph to figure 4.**
  The figure shows you what your graph will look like:
  a if the relationship is proportional;
  b if the relationship is linear;
  c if the relationship is quadratic;
  d if the relationship is inversely proportional.

The (u,F) diagram for a helical spring is a straight line through the origin (figure 3). This shows you that that, for a helical spring, the extension is directly proportional to the force.

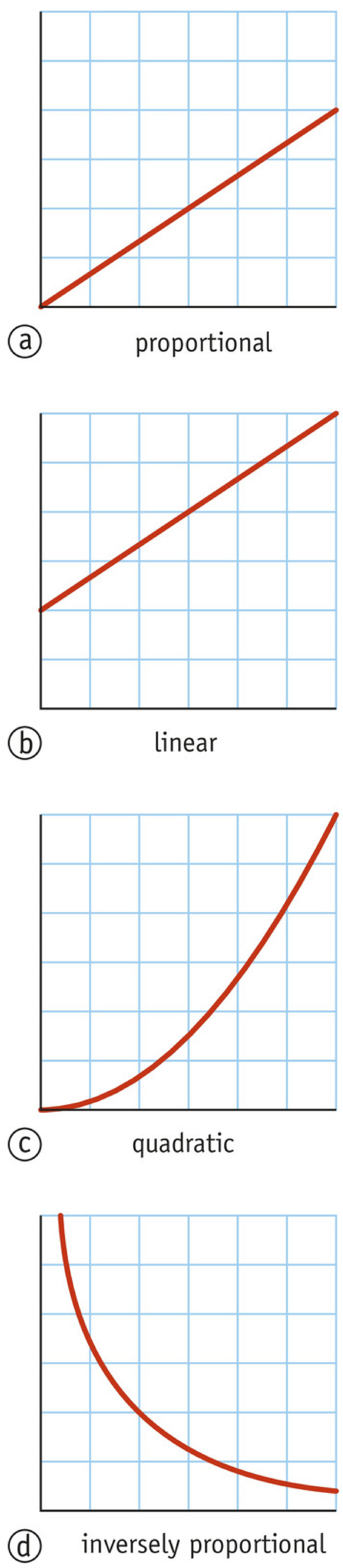


figure 4
four types of relationships

9 Making a design

Making a design starts with a problem and ends with a properly working solution. To get to that solution, you take a step-by-step approach.

- **Step 1: Analysing the problem**
  First of all, you have to find out exactly what the problem is. You ask whoever has set you the problem exactly what the situation is now and how it has to end up. Then you describe the problem in the most concrete terms possible.

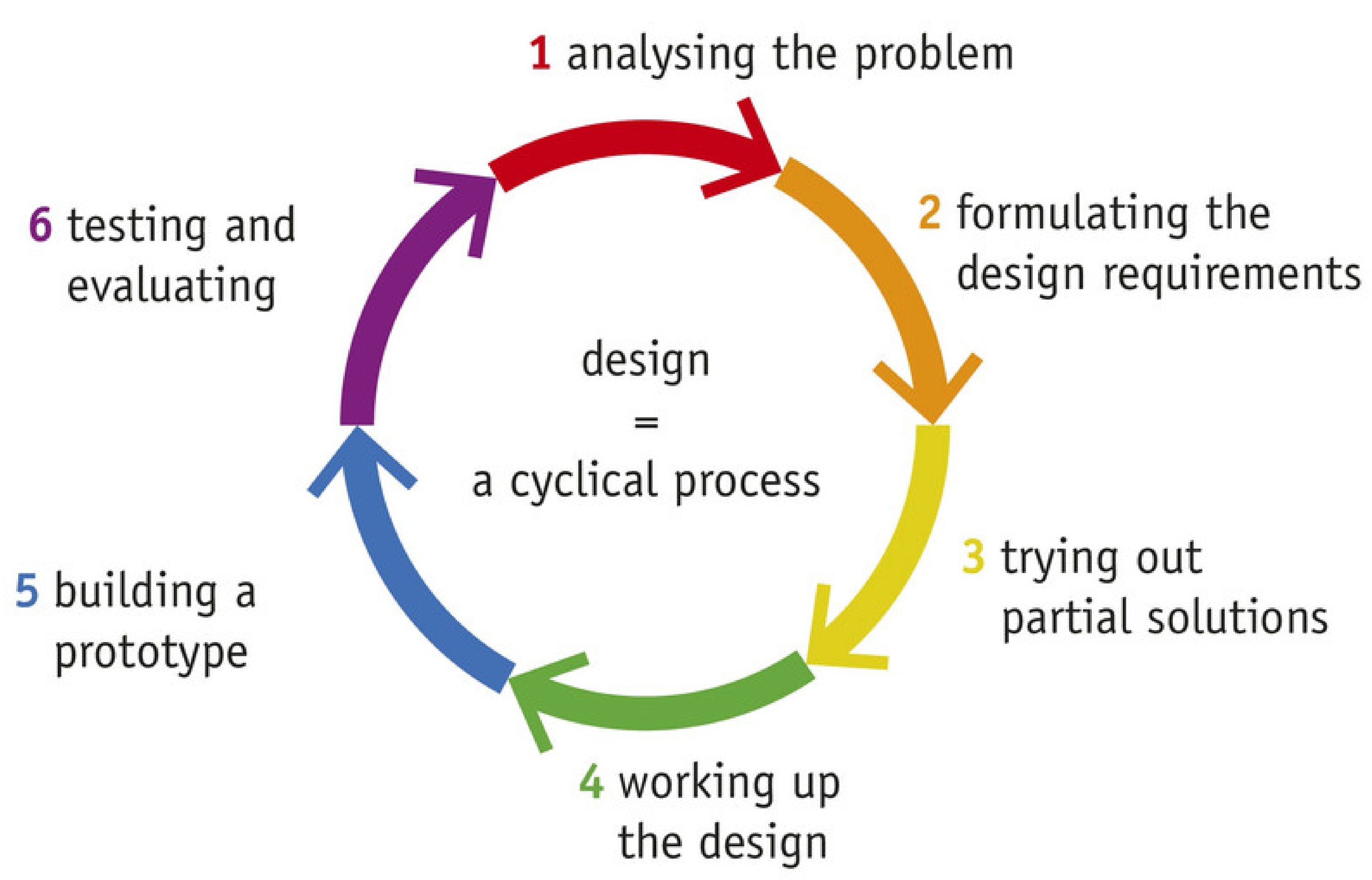
- **Step 2: Formulating the design requirements**
  You make a list of the requirements that the solution has to meet. You make sure that those requirements are clear and can be properly tested. You have to be able to determine whether each of the requirements has been met.

- **Step 3: Trying out partial solutions**
  You do not usually get a complete design in one go. You first think up partial solutions for parts of the problem and test whether they work properly. That lets you keep a clear picture of the design process.

- **Step 4: Working up the design**
  Once you have enough information about the partial solutions, you can work up a complete design that meets all the design requirements. You describe the design clearly and completely, with texts and pictures.

- **Step 5: Building a prototype**
  You construct a prototype or model that lets you test the design: a more or less improvised (but fully functional) version of the design. That may be at the correct size or a scale model.

- **Step 6: Testing and evaluating**
  Finally you will test whether the design works properly in practice. You check carefully whether it meets all the design requirements. If you find any problems, you find solutions for them that you then test again.



These six steps are often repeated several times, either in full or in part. This is why they are sometimes referred to as the design cycle (figure 5).

◀ **figure 5**
the design cycle

10 Writing a report

Research has to be written up. In the report, you explain what happened during the experiment. Somebody who was not actually there must be able to understand exactly what happened.

Lay your report out like this:

- **Title page**
  This gives the title of the report, the names of the pupils in the group doing the experiment, the name of your teacher and the date and year.

- **Section 1 Study question**
  This section is where you explain what question you wanted your study to answer.

- **Section 2 Work plan**
  This contains:
  a the variables you have measured;
  b the practical equipment you have used;
  c the setup you made (make a sketch);
  d precisely what you did:
    – What measurements did you carry out?
    – How have you processed the measurements (drawings/calculations)?
    – What calculations did you do (including the formulae)?

- **Section 3 Experimental results**
  This is where you state what you have observed or measured, as texts, tables, graphs, photos and so forth.

- **Section 4 Conclusions**
  The answer to the study question can be stated here. You also say what could have been done better.

A report should look good. It is not only about the information that your report contains: you must also present that content clearly and neatly. A number of useful pointers:
– Use A4 size paper.
– Make sure there is plenty of space at the margins: top and bottom, left and right.
– Choose an easily legible font, with a large enough size.
– Place a heading in bold above each section. Then skip a line.
– Make sure that the drawings, tables and graphs are neat. Add a number to each so that you can refer to them in the text.

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